Semi-Autonomous Vehicles: A Closer Look at the Take-Over

A pivotal area of research focuses on the human factors elements incorporated with autonomous vehicles, specifically, understanding how drivers adopt and interact with this technology, identifying the challenges that a driver may face during the interaction and considering these issues and challenges in the design of the driver-vehicle interface are critical to the success of this advanced technology. Previous analyses suggested that take-over – the time in which an individual regains control of the vehicle – is one driving period that could raise critical safety concerns. This on-going study aims to observe how drivers perform during the critical take-over period. In addition, this study also explores the effectiveness of warning to take-over intervals (warning given 7.5 seconds or 4.5 seconds before take-over).

Some trends in the preliminary results are emerging; particularly a possible improved performance over three sections of drives (4 take-overs in each section). Findings and future directions are discussed.

INTRODUCTION

According to the U.S. Department of Transportation (2013), in 2012, over 33 thousand people died in motor vehicle crashes, and 2.36 million people were injured in the United States. The industry has been tirelessly working towards creating a safer driving environment, and autonomous vehicle technology has been proposed as a potential solution. Companies like Volvo, Nissan and even NASA have issued statements with the desire to implement an autonomous vehicle by 2020 (Los Angeles Times, 2015; Nissan, 2015). Due to this accelerated interest, the National Highway Traffic Safety Administration (NHTSA) has made autonomous vehicle technology research a primary point of focus (NHTSA, 2013, 2014) and has described 5 total levels for vehicle automation (NHTSA, 2013).

It is estimated that autonomous vehicles could be introduced as early as 2020. However, this technology may not be fully adopted by the majority of the population until approximately 2060 due to vehicle cost and selective location availability (Littman, 2015). Given the fast pace of technology innovation, human factors research is needed to understand driver behavior when interacting with each level of autonomous driving.

The NHTSA has placed an importance in research on autonomous vehicle technology, specifically the human factors elements that are incorporated in take-overs such that “drivers can safely transition between automated and non-automated vehicle operation” (NHTSA, 2013). According to the NHTSA (2013) a warning should be provided to the driver in an autonomous vehicle prior to any transition or take-over. A sufficient warning to take-over interval is essential to allow the driver to fully assess the situation and re-engage in the driving task. It is important to design the driver-vehicle interface to support seamless transition. A few assistive systems are being developed, including vehicle route planning and path mapping, placement of sensors, vehicle display units, collision avoidance (Bergbolz, Timm, & Weissier, 2000), long range radars and GPS tracking (Los Angeles Times, 2015), vehicle to vehicle communication (NHTSA, 2014), and gesture control (BMW Group, 2015).

A systematic understanding of driver behavior during take-over period is highly necessary. Research in other domains (e.g., aviation) can broaden our understanding about automation and can provide insight to the potential and hindrances of the technology. For example, previous research identified important considerations on system error (Sarter & Woods, 1997), over-reliability (Parasuraman & Riley, 1997) under-reliability (Endsley & Kiris, 1995, Kaber, Onal, & Endsley, 1995), and communication errors (Hollands & Woods, 1997).

A few pioneering projects have started looking at driver engagement and disengagement using eye tracking (Merat, Jamson, Lai, Daly, & Carsten, 2014) as well as path mapping via eLane measuring standard deviation of lane position, mean and minimum longitudinal velocity, steering wheel angle input, time headway and time to contact (Merat, Jamson, Lai, & Carsten, 2014).

As a first step to understand driver behavior during take-over in semi-autonomous driving, this research focuses on answering two questions: 1) how do drivers react after they have been disengaged from the task of driving in a semi-autonomous vehicle (e.g., level 3); 2) how do drivers adapt and learn with accumulating experience in transition. This study aims to observe driver behavior during the take-over (the brief period of time after driver regains control from the vehicle) between manual driving and an artificially designed and simplified level 3 autonomous driving. In addition, this study also explores how drivers learn to take over with increasing experience.

METHOD

We simulated partial-autonomous driving in a driving simulator. Take-over scenarios were activated when the vehicle approached a construction zone (thus the driving environment became much more complex and human operation was needed). This study aims to explore how participants handle a take-over during partially automated driving. Moreover, the study was also designed to examine whether warnings of two different warning to take-over intervals (i.e., how much in advance was the warning provided) differ in terms of their effectiveness, as well as how drivers’ take-over performance would change over time.

Participants

This is an ongoing study. By the time of writing up this proposal, we have tested five participants (all male, undergraduate students, age range (19-21). These participants...
were gathered from the University’s Experimetrix website which is where students may sign up for participants and receive course credit in exchange for participation. In this proposal, we present some preliminary results from the observations of the five participants.

Materials

Simulated driving. Driving simulation was run on a console version of STISIM Drive 3 (Figure 1). The simulation was displayed on three adjacent 42-inch television screens. The graphics were presented at 1920 x 1080. The simulator is consisted of a steering wheel, and driving pedals. Participants were allowed to adjust the seat according to their personal preferences. The simulator collected various driving performance measures and at a rate of 60Hz. Two auditory notifications were used to indicate the upcoming transition from automation to manual driving (i.e., driver taking over) and from manual driving to automation (i.e., manual driving will end and automation will be activated). The warning for an upcoming take-over was two beeps of first 400 Hz and then a successive beep of 350 Hz. The notification of the upcoming activation of autonomous control was two beeps of first 350 Hz and then 400 Hz.

Figure 1: STISIM Drive 3 Simulator

Questionnaire measuring opinions concerning autonomous driving. We have adapted a questionnaire (Schoettle and Sivak, 2014) for measuring opinions of drivers concerning autonomous vehicles to assess our participants’ familiarity to autonomous driving and opinions of the driving situations that we developed. Participants completed this self-report questionnaire before and after completing simulated driving. By collecting opinions from every participant twice, we may be able to identify the potential changes in their opinions regarding partially autonomous driving with accumulating experience.

Procedure

Participants first completed an online version of the questionnaire. They then participated in the experiment session in the lab. Participants were provided a consent form as well as a brief demographic survey.

Once they had completed all of the surveys, the participants were provided instructions about the simulated driving task. The notification sounds (warning for driver take-over, warning for automation about to start) were played to the participants and explanations were provided for both. Participants then practiced simulated driving during a practice drive which was based off of the experimental drives. During this drive, participants experienced a simple driving route with stop signs, and also two transitions from computer controlled drive (partially autonomous) to manual and vice-versa. Sound notifications of the state changes were provided in advance before a transition took place. Participants were allowed to repeat the practice if they desired additional time. Prior to the practice, participants were encouraged to direct any questions to the experimenter. Participants then completed the experiment session.

The experiment session consisted of three drives. The vehicle was centered in a rural highway environment with construction zones placed at specific intervals. Each drive was a total of 12.52 km, and the set speed limit during the autonomous portion was 67.5 km/h, and that same speed limit remained the advised speed throughout the manual drives. Each drive contained four manual zones (designed as construction zones) which expanded a constant distance of 0.94 km, and four autonomous driving sections were presented in each drive. Each autonomous driving sections was of either 1.81 km or 2.41 km. These distances were selected based on time, with each autonomous drive will last 1.5 minutes (1.81 km) or 2 minutes (2.41 km). Two distances of autonomous driving were used instead of one, in order to induce disengagement and also to reduce the repetitiveness and predictability of the take-over timing. An overview of the procedure is illustrated in Figure 2. Given greater familiarity to imperial units than to the metric units of our participants, we presented imperial units in our scenarios. We converted these measures into metric units for the presentation of this proposal.

Design

The drives were designed to resemble a 4 lane rural highway, with various trees placed outside of the roadway. The autonomous portion contained oncoming vehicles. During this portion, the system was designed to control both the speed and lane position. Although the scenario attempted to mimic a level 3 autonomous vehicle (limited self-driving capabilities) within the capability of our simulator, we are very aware of the limitations of our scenario to study partially autonomous driving.
The computerized controls were in fact level 2 (two advanced functions, including a cruise control and a lane position control, operating simultaneously). To be successful in our mimicry, we did not include any sudden objects on the road during these intervals, thus the vehicle appeared to drive itself during the autonomous drive and no input was required from participants. In addition, participants were instructed that the vehicle would drive itself during some period, but transition between autonomous drive and manual drive would take place after warning sounds were presented and the vehicle would initiate these transitions. By these designs, the participants were in a driving situation that involved more than level 2 autonomous driving, more similar to level 3.

The manual driving portions were designed as construction zones (Figure 3). During manual driving, participants controlled all aspects of the vehicle (e.g., lateral control, longitudinal velocity control). There were six different construction zones that were designed and each was presented twice and in a randomized order in the three drives.

RESULTS

The measures collected for analysis include drivers speed (average speed, and the minimum speed), standard deviation of lane position, brake input and throttle input. These measures were collected for the entire manual driving portion, however to single out the take-over, we specifically analyzed the 0.12 km zone that occurred immediately following the take-over, this distance will be called the take-over zone. There were 6 repetitions of each warning to take-over interval condition within participants during which these measures were collected. In addition to analyzing the two warning intervals, we were interested in examining the difference among the three drives. Although a sample size of 5 is much smaller than the desired number to properly detect any effect that we were interested in, given ANOVA is in general a robust test, we did a 3 by 2 repeated measures ANOVA (drive by warning interval) for each of the measures listed above to examine the trend of potentially emerging results. In the following results sections, we only noted effects with a p value smaller than .30 which may be suggesting some trends. The main focus of analysis at this stage is to examine the patterns as indicated by the mean values of each measure across conditions.

Longitudinal Velocity

The participant’s average speeds (km/h) over the entire manual drive for both warning interval conditions are illustrated in Figure 4. As seen, there is a general trend of a decrease in speed during take over. In the analysis, we examined both average speed and minimum speed during the task over period.

Table 2

<table>
<thead>
<tr>
<th>Condition</th>
<th>Drive 1</th>
<th>Drive 2</th>
<th>Drive 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>39.88</td>
<td>45.52</td>
<td>56.68</td>
</tr>
<tr>
<td></td>
<td>-2.46</td>
<td>-2.31</td>
<td>-2.22</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>.069</td>
<td>.082</td>
<td>.090</td>
</tr>
<tr>
<td>2</td>
<td>40.89</td>
<td>51.14</td>
<td>51.45</td>
</tr>
<tr>
<td></td>
<td>-2.02</td>
<td>-2.01</td>
<td>-2.01</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>.113</td>
<td>.115</td>
<td>.115</td>
</tr>
</tbody>
</table>

To analyze this decrease in speed, a t-test was conducted for each drive and condition (comparing the minimum speed to the preset 67.5 km/h). A possible trend of a difference between minimum speed and the set speed emerged at take-over, in particular for Condition 1.

The overall means on average speed during take-over showed some difference between the three drives, with a general trend of increasing average speed across the three drives (M_{drive_1} = 48.73, M_{drive_2} = 57.70, M_{drive_3} = 59.82) during the take-over zone for the drives. There was a trend observed in significance testing, F(2, 8) = 2.48, p = .145. Not much difference was observed on average speed during take-over between the two warning interval conditions (M 7.5s warming = 56.31, M 4.5s warming = 54.52) and in general no trend of interaction. Similarly, the means of minimum speed looked different with a trend of increasing minimum speed from Drive 1 to Drive 3 (M_{drive_1} = 40.39, M_{drive_2} = 48.33, M_{drive_3} =
54.07), with a very weak trend in significance testing, $F(2,8) = 1.60$, $p = .26$. Not much trend was found about the difference on minimum speed during take-over between the two warning intervals ($M_{7.5s\;\text{warning}} = 47.36$, $M_{4.5s\;\text{warning}} = 47.83$), or any interaction between drive and warning interval. The change of means across conditions are illustrated in Figure 5 (minimum speed), Figure 6 (average speed).

![Figure 5](image1.png)

**Figure 5:** Minimum Speeds by Condition over Drives. Condition 1 the warning is provided .15 km before take-over and Condition 2 the warning is provided .09 km before take-over.

![Figure 6](image2.png)

**Figure 6:** Average Speed by Condition over Drives. Condition 1 the warning is provided .15 km before take-over and Condition 2 the warning is provided .09 km before take-over.

### Standard Deviation of Lane Position

In addition to longitudinal velocity, lane position of the vehicle during take-over could be another driving performance measure showing the smoothness of take-over. No trend emerged for means during the take-over zone of the drives ($M_{\text{drive}1} = 7.89$, $M_{\text{drive}2} = 8.80$, $M_{\text{drive}3} = 6.24$), however there is a potential trend emerging between the means for the two warning interval conditions ($M_{7.5s\;\text{warning}} = 6.79$, $M_{4.5s\;\text{warning}} = 8.51$). This trend was observed with significance testing, $F(1,4) = 60.6$, $p = .001$.

### Brake and Throttle Input

Furthermore, we examined the brake input as well as the throttle input during take-over. This measure was selected to determine if there were any significant relations as to how a participant decreased their speed. There appears to be a general decrease in brake input across the drives ($M_{\text{drive}1} = -1.23$, $M_{\text{drive}2} = -1.13$, $M_{\text{drive}3} = -.77$), however there was no trend observed in significance testing. Similarly, there was no observed trend in the throttle input ($M_{\text{drive}1} = 1.82$, $M_{\text{drive}2} = -1.64$, $M_{\text{drive}3} = 1.96$), where there was no observed trend via significance testing either.

### DISCUSSION

This study aimed to examine driver behavior during a take-over that could take place when driving a limited self-driving vehicle (level 3 autonomous). We observed this take-over by using two warning conditions, and over a period of three drives. Despite the small sample size, we observed some patterns and trends. With more data, we will be able to properly examine the significance of these patterns.

One interesting trend was the potential improvement in driver performance during task-over in the three drives, as the speed change became less dramatic over the drives. This may imply the need for training when introducing partially autonomous driving during which take-overs may occur. This finding further supports suggestions made by NHTSA (2013) that training procedures need to be considered. There does not seem to be any significant difference between the two warning conditions in regards to speed, however there is a significant difference in warning condition for lane position. This would imply that the longer warning (.15 km) lead to better driver control and consistency of the vehicles lane position at take-over.

Moreover, the general trend seen in speed overall by participants cause some concern regarding traffic flow. This decrease in speed that results after take-over could trigger the shockwave effect. The shockwave effect is a traffic phenomenon which occurs when the traffic flow is disrupted by a decrease in speed (e.g. accident, distraction) (May, 1990).

### Limitations

The STISIM Drive 3 simulator did not support the development of a truly limited self-driving automation with level 3 control, therefore we attempted to mimic this level of automation within the technical possibilities by limiting the possible events during driving. During the autonomous drive, there were no events which would trigger a response from the vehicle, considering the only functions we had available were speed control and lane position control. Participants were instructed that the simulated driving was operating as a level 3 vehicle. Therefore, results from this study may not generalize to a real autonomous driving situation given the technical dif-
ferences and participants’ beliefs in whether they were interacting with a highly autonomous driving situation (although our anecdotal observation of the 5 participants so far seem to believe that). However, the results are interesting and further analyses of data from a sufficient sample size could be informative. Of course, validation of the results in a more advanced simulator or even naturalistic driving could significantly improve the generalizability of the results.

Another limitation is due to the simulator’s inability to collect driver performance during the autonomous portions. As a result, it was difficult to obtain measures of driver performance right after a warning was given and before a takeover happened. We have recorded videos of participants’ behavior during driving (e.g., facial expression, hands and feet movement). These observational data may provide some insights into drivers’ behavior during the take-over period.

**Future Study**

This study was primarily exploratory, and it’s main goal was to provide a platform for further analysis. It’s results introduce some possible implications of the take-over and also lead to various considerations that could be made in many aspects of autonomous driving (e.g., training, traffic flow). Additionally, comparing results between young participants (current population) and elderly participants would be useful. This would provide insight as to how to design these vehicles with all populations being considered.

Another main aspect of this study that is to be continued is the incorporation of the survey that is administered both before and after the experimental drive. This survey could provide insight into driver’s opinions regarding this technology and their performance (i.e. if a driver does not trust the technology, they may perform worse).

**REFERENCES**


http://www.bmwgroup.com/e/0_0_www_bmwgroup_com/forschung_entwicklung/technologie/connected_drive/zukunft_connected_drive.html


