Tunneled In: Drivers with Active Secondary Tasks Need More Time to Transition from Automation

Brian Mok*, Mishel Johns*, David Miller†, Wendy Ju*
Department of Mechanical Engineering* and Communication†
Stanford University, Stanford, CA, USA
{brianmok, mishel, davebmiller, wendyju}@stanford.edu

ABSTRACT
In partially automated driving, rapid transitions of control present a severe hazard. How long does it take a driver to take back control of the vehicle when engaged with other non-driving tasks? In this driving simulator study, we examined the performance of participants (N=30) after an abrupt loss of automated vehicle control. We tested three transition time conditions, with an unstructured transition of control occurring 2s, 5s, or 8s before entering a curve. As participants were occupied with an active secondary task (playing a game on a tablet) while the automated driving mode was enabled, they needed to disengage from the task and regain control of the car when the transition occurred. Few drivers in the 2 second condition were able to safely negotiate the road hazard situation, while the majority of drivers in the 5 or 8 second conditions were able to navigate the hazard situation safely.

Author Keywords
Car Simulator; Controlled Study; Autonomous Vehicles; Transition of Control; Human Machine Interaction.

ACM Classification Keywords
H.1.2. User/Machine Systems.

INTRODUCTION
With automated driving systems in the future, it is expected that drivers will not be required to maintain vigilance in monitoring the car's activity and will be given the freedom to perform other secondary tasks. However, there will still be scenarios where it will be necessary for the driver to take over control of the vehicle. Given the various states of distraction that drivers may be in when a transition of control is required, it is important to understand how they would react in these emergency situations. This insight would then allow us to better craft safety standards and augment existing policies for automated driving. For example, in the National Highway and Traffic Safety Administration's (NHTSA) levels of automation paradigm, it is stated that vehicles of Level 3 automation (Limited Self-Driving) should provide drivers with "sufficiently comfortable transition time" when taking back control [12]. This subsequently dictates how far in advance automated vehicles need to perceive events or hazards, an important design requirement for auto manufacturers. NHTSA has not defined how long this time should be and has indicated that further evaluation is need. So, a worst-case benchmark must be established to determine this minimum necessary time.

CHI 2017, May 06-11, 2017, Denver, CO, USA
 ISBN 978-1-4503-4655-9/17/05$15.00
DOI: http://dx.doi.org/10.1145/3025453.3025713

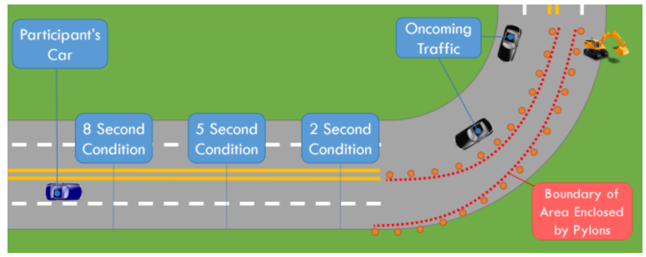

Figure 1: Diagram of the Critical Transition Event

This study (N=30) was conducted with a driving simulator, in which the human driver and an automated driving system could alternately control the vehicle. While the car's automated driving system was in control, the participants were asked to perform an active secondary task (i.e., playing a game on a tablet computer). As the car continued to drive autonomous in the freeway section of the simulation scenario, it would suddenly encounter a road hazard. After an emergency alert was issued from the vehicle, the driver needed to disengage from the secondary task to negotiate the hazard. An unstructured transition, in which control is immediately returned to the driver, was utilized. Three different transition conditions were tested, with the unstructured transition occurring 2 seconds, 5 seconds, or 8 seconds before the road hazard. The post-transition driving performance and post-drive attitudes of the participants toward the car were examined. These results help determine how much time is needed for drivers to assess the situation and successfully regain control.

BACKGROUND
This study seeks to understand how drivers react when control of the vehicle is suddenly relinquished back to them from the automated driving system. In the framework of automated vehicles, the takeover time for unstructured transitions of control have not been extensively examined. While there have been some studies that utilized

unstructured transitions, such as Louw et al. who observed performance differences between automation conditions [8], the experiment designs did not present a worst-case scenario as the participants were informed in advance to expect a transition. In our prior works [9] [10], the participants were only subjected to a single challenging critical event, which prevented any priming or learning effects. Subsequently in both studies, very significant differences in post-transition performance were observed between the different transition time conditions (2 seconds, 5 seconds, and 8 seconds) tested. The effects of secondary tasks were also examined. The participants were instructed to monitor the car in our first study [9] and watch a video in our second study [10]. However, there was no significant difference in performance with regards to the secondary task, possibly since these two tasks were less taxing. Thus, in this third study, it is vital to investigate the effects of a secondary task that requires much more active engagement—playing a game—to determine a minimum time required for transitions.

Structured transitions, in which drivers are given a period of time to get ready to resume control while automation continues to drive, do not present a worst-case scenario that can be used to determine a minimum time. However, there are many studies that use this paradigm to examine driver behavior. Damböck et al. tested several takeover times and determined that notifications greater than 8 seconds might not lead to greater post-transition driving performance [5]. Many studies also examined the effects of secondary tasks on drivers' performance [3] [7] [13] [15]. Gold et al. found that distracted drivers given shorter takeover request times tended to respond quicker but exhibited worse performance [6]. Beukel et al. found a similar result, with longer advanced warnings leading to more successfully avoided collisions by distracted drivers [1]. NHTSA also tried to determine "sufficiently comfortable" time in their on-road driving study [2]. However, only reaction time, not post-transition performance, was examined in this study.

METHODOLOGY

Simulator

The first component of our high-immersion fixed-base driving simulator is a modified Toyota Avalon, which provides an immersive full car interface. To increase the presence of the simulator [8], haptic feedback is incorporated into the steering wheel and pedals. The other component of the driving simulator is the audio/visual display. A 270-degree field of view cylindrical screen surrounds the car. The videos of five projectors blend together to create a seamless simulated driving environment. A sixth projector is used to display the rear view and LCD panels are installed in the side view mirrors. External speakers and a subwoofer simulate road noise, which varies from 40 to 55 dB (measured from driver's seat). Speakers inside the cabin provide audio alerts from the car to the participant at 50 dB. Several *GoPro* cameras

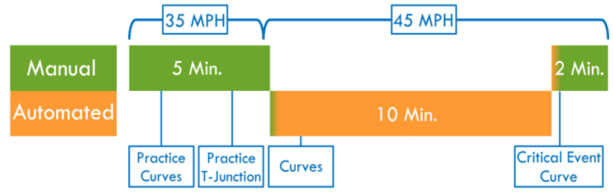

Figure 2: Diagram of the Simulated Driving Course

are installed inside the car's cabin so that driver's behavior during the study can be monitored and recorded. *Realtime Technologies' SimCreator* software is used to create the audio and visual components of the simulation.

Course

During the duration of the course, the automated driving mode would perform the majority of the driving task. As Figure 2 shows, there are three different sections in the course. The first 5-minute section was designed to allow the participants to practice and become acclimated to driving in the simulator. At the end of this first section, participants were asked to enable the automated driving mode and the vehicle drove on for 10 minutes in the second section. This second section was mostly composed of a long segment of straight road, but also contained several curves at the beginning to demonstrate that the automated driving mode was normally capable of negotiating many road types. This was important due to the design of the critical event.

At the beginning of the last section, the car approached a curve which lacked lane markings. It was designed to appear as though construction was in progress (Figure 1). A set of pylons was placed to indicate where the center divider was located. Another set of pylons was used to close off the right lane (where an excavator was placed) and force the participants to stay in the left lane. This area provided a realistic scenario in which the car's automated driving system might have difficulty negotiating in real life. As this scenario required participants to both comprehend the situation and then react accordingly, it was an excellent indicator of participants' ability to regain control of the car.

Full control of the car was returned to participants a few seconds (i.e., 2, 5 or 8 seconds) before entering this critical event. An audible alert, "Emergency, Automation Off," and a visual alert on the instrument cluster indicated that the unstructured transition had occurred. The control of car was instantly given back to the participants in the drive mode, with the steering wheel centered, and with no additional input to the brake or throttle. Once the car entered the curve, traffic was spawned in the two oncoming lanes to encourage the participants to stay between the pylons and not take evasive actions in that direction. After the event, the participants drove manually until the end of the course.

Transition Time Manipulation

Based on prior research and related works, 2 seconds, 5 seconds, and 8 seconds were chosen to be the three transition time conditions for this study. The transition time was defined to be the amount of time it took for the car to reach the lane closure. For every condition, the car would travel at 45 mph (chosen based on the road type used) at the point of transition, and would always enter the critical event in the left lane. Given the speed and lane position when transition occurred, the transition point for each condition was placed at an appropriate distance from the pylons.

Secondary Task

Participants were instructed to do an activity while the car's automated driving mode was enabled. They were given an active secondary task in the form of playing a game on an iPad. The game selected was the popular iOS application: *Temple Run 2*. It was a good application for the study because it required the participants to be constantly engaged to play effectively. Unlike other games that allow for breaks during play, *Temple Run 2* is a perpetual experience where the players need to avoid obstacles that appear every few seconds. As the game became harder and faster over time, it could be very taxing on the participants and add an element of fatigue. To see how they would naturally disengage from this task, participants were not told what to do with the iPad in the advent of an emergency.

Procedure

The participants were first asked to sign a consent form and complete the pre-drive questionnaire. They were then led into the driving simulator room. To ensure that they would only be engaged with the given task, the participants were asked to relinquish their electronic devices during the study. They were briefed on the vehicle's automated driving system and how to enable it. They were instructed to play the game on the tablet when the automated driving mode was on; participants were encouraged to aim for the high score and to play again if they lost in the game. To establish a worst-case benchmark, participants were not informed of the transition in advance and were not additionally incentivized to perform well in the driving task. Overall, the simulated driving task took 15 to 20 minutes to complete. After finishing the driving task, participants were asked to complete the post-drive questionnaire.

Participants

A total of 30 participants were recruited for the study. The participant population had an age distribution that ranged from 17 to 59 years old (M = 32.3 years, SD = 10.8 years). Their reported years of driving experience ranged from 1 year to 44 years (M = 12.2 years, SD = 11.4 years). Genders of the participants were equally distributed across each condition, 50% male and 50% female.

ANALYSIS

Driving Behavior Data

The simulation driving data (position in the road, driver inputs, etc.) was collected at 60Hz. The driving metrics selected for analysis allowed for a better understanding of how participants performed on the curve. Given how the transition and critical event were designed, certain other traditional metrics for takeover, such as time to evasive action, were not appropriate for evaluating performance. For example, several participants in the 8 second condition did not instantly detect the road hazard as they were still far away from the critical event. This led to a slower reaction despite good performance. The data was analyzed using Python to extract measures of driving performance and *R* to perform the various statistical tests. The following measures were calculated over the duration of the curve.

Negotiating the Critical Event

From the road offset, it can be determined if the car stayed within the appropriate area that was enclosed by the pylons. By using position of the pylons, the boundaries for this area can be defined as a set of two equations with regards to road offset (see Figure 1). A binary measure of whether the curve was successfully negotiated without a collision into the pylons showed a significant difference between conditions on the Chi Squared test (χ^2=9.55, df=2, p<0.01). All participants in 8 second condition negotiated the curve successfully, while 8 of the 10 participants in 2 second condition and 4 of the 10 participants in 5 second condition failed. Video analysis also confirmed this finding.

Standard Deviation of Road Offset

The distance of the vehicle from the centerline of the road (variation in road offset) can be used as a measure of driving performance. [14] [4] This is similar to a measure defined by SAE J2944 [16]: the standard deviation in lane position. Control was returned to the participants with the steering wheel was centered. This initial steering wheel position should not cause any detrimental artifacts on the standard deviation of road offset post-transition. Performing ANOVA, the standard deviation of the road offset (in meters) in the curved section of the road showed significant differences between the conditions. However, as one of the groups was non-normal (Shapiro-Wilk Normality test p = 0.017 for the 5 second group), the non-parametric Kruskal-Wallis rank sum test was used to confirm the result. The test showed significant differences between the transition time conditions, χ^2=18.49, df=2, p=9.67e-5. Conducting the post-hoc pairwise analysis using the Wilcoxon rank sum test with Bonferroni correction showed differences between the 5 second (M=0.6, SD=0.46) and 2 second (M=1.88, SD=0.84) conditions (p<0.01) and significant differences between the 8 second (M=0.28, SD=0.12) and 2 second conditions (p<0.001) and moderately significant differences between the 8 second and 5 second conditions (p=0.10).

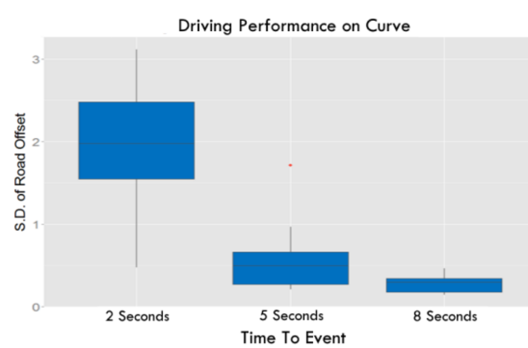

Figure 3: Road Offset Standard Deviation

Standard Deviation of Steering Wheel Position

Standard deviation of the steering wheel position (in radians) [4] is also used to measure driving performance. The measure passed the Shapiro-Wilk test of normality ($p > 0.1$) but failed the Levene's test for Homogeneity of Variance ($p < 0.05$), so the non-parametric Kruskal-Wallis rank sum test was again used. The test showed significant differences between transition time conditions, χ^2=12.68, df=2, p=1.7e-3. A post-hoc pairwise analysis using the Wilcoxon rank sum test with Bonferroni correction showed significant differences between the 5 second (M=0.48, SD=0.33) and 2 second (M=1.29, SD=0.85) conditions ($p<0.05$) and significant differences between the 8 second (M=0.19, SD=0.08) and 2 second conditions ($p<0.01$) and moderately significant differences between the 8 second and 5 second conditions (p=0.10).

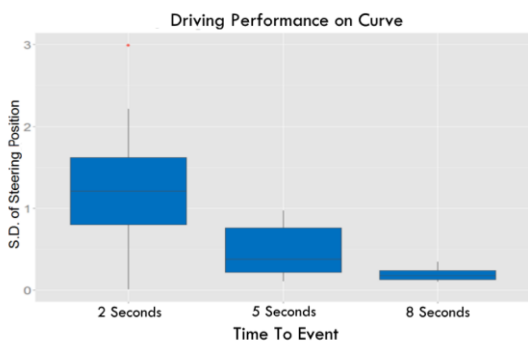

Figure 4: Steering Wheel Position Standard Deviation

Initial Evasion Strategy

To determine if the time conditions affected or limited participants' decision making, their initial evasion strategy (brake first vs. steer first) was examined. Of those participants who tried to brake first, there were 6 in the 2 second condition, 7 in the 5 second condition and 8 in the 8 second condition. Performing a Chi Squared test (χ^2=0.952, df=2, p=0.621), no significant differences were found.

Disengaging from the Task

Through video analysis, we examined how participants disengaged from playing the game when they were prompted to take over control. Most participants (28/30) dropped the tablet on the passenger seat or on their lap. There were 2 participants tried to hold on to the tablet while negotiating the critical event. Surprisingly, 5 participants tried to pause the game even after hearing the alert.

Attitudinal Data

In part of the post-drive questionnaire, participants were asked how well certain words described the automated driving system. A 7-point Likert Scale was used (1 = *describes poorly*; 7 = *describes well*). Performing ANOVA, no significant differences were found.

DISCUSSION AND RESULTS

It appears that the 2 second transition time condition does not provide sufficient time for the participants to regain control and negotiate the road hazard. Participants in this condition performed significantly worse than those in the other two conditions. The participants in the 2 second condition exhibited both a significantly greater road offset standard deviation and steering wheel standard deviation during the event. Also, a large majority of these participants hit the critical event's pylons. Eight participants were unable to stay in the lane and some participants even drove straight ahead into the grass, which was rarely observed in previous studies. So, any transition from automation should occur more than two seconds before the critical event.

Similarly, the 5 second condition also appears to be not sufficient, as a few lane deviations or collisions with pylons still occurred. Four of the participants were unsuccessful in negotiating the critical event. While the participants in the 5 second condition appeared to perform significantly better than those of the 2 second condition, they also did not perform as well as those in the 8 second condition.

The participants of the 8 second condition did not deviate from the critical event's left lane or hit any of the pylons. It is the shortest of the tested transition times that has yielded excellent driver performance. Hence, the minimum amount of time required for drivers to regain control should be between 5 and 8 seconds, which is a range that automotive manufacturers should consider when designing cars.

We also noted an interesting result in the analysis of the self-reported attitudinal data. In previous studies, there were significant differences in how trustworthy the car appeared to the participants and how much participants liked the car. However, we did not see any significant difference between conditions for this study. Interestingly, participants in the 2 second condition in this study had a much wider range of responses compared to those participants in prior studies.

CONCLUSION AND FUTURE WORK

This study has yielded significant results on how drivers performed post transition with automated driving systems. There appears to be a minimum amount of time needed for transition of control, between 5 seconds and 8 seconds. The results of this study (where the participants were given an active secondary task) are not similar to those of our prior studies (where the participants were given no task or a passive secondary task). In both previous studies, the 2 second condition is also not long enough, but the 5 second condition is adequate for transition of control.

In our future work, we want to test the effectiveness of different alert modalities. While it is established that having both audio and visual alerts are important [11], do drivers perform better when given other types of alerts, such as haptic or movement-based? Additionally, we also seek to validate these results by performing an on-road study.

ACKNOWLEDGMENT

The authors thank Jan Becker, Key Lee, Srinath Sibi, and Nikhil Gowda for their contributions to the study. The project is supported by Robert Bosch LLC.

REFERENCES

1. Arie P. van den Beukel and Mascha C. van der Voort. 2013. The influence of time-criticality on Situation Awareness when retrieving human control after automated driving. In 16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013), 2000–2005.
2. Myra Blanco, Jon Atwood, Holland M. Vasquez, Tammy E. Trimble, Vikki L. Fitchett, Josh Radlbeck, Gregory M. Fitch, Sheldon M. Russell, Charles A. Green, Brian Cullinane, and others. 2013. Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts. Vergina Tech, Automated Vehicle Systems Group Research.
3. Avinoam Borowsky and Tal Oron-Gilad. 2016. The effects of automation failure and secondary task on drivers' ability to mitigate hazards in highly or semi-automated vehicles. *Advances in Transportation Studies*, 1.
4. Karel A. Brookhuis, Gerbrand de Vries, and Dick de Waard. 1991. The effects of mobile telephoning on driving performance. Accident Analysis & Prevention 23, 4: 309–316.
5. Daniel Damböck and Klaus Bengler. Übernahmezeiten beim hochautomatisierten Fahren.
6. Christian Gold, Daniel Dambock, Lutz Lorenz, and Klaus Bengler. 2013. "Take over!" How long does it take to get the driver back into the loop? Proceedings of the Human Factors and Ergonomics Society Annual Meeting 57, 1: 1938–1942.
7. Toshio Ito, Arata Takata, and Kenta Oosawa. 2016. Time Required for Take-over from Automated to Manual Driving.
8. Tyron Louw, Natasha Merat, and Andrew Hamish Jamson. 2015. Engaging With Highly Automated Driving: To Be Or Not To Be In The Loop? In 8th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 189–195.
9. Brian Mok, Mishel Johns, Key Jung Lee, Hillary Ive, David Miller, and Wendy Ju. 2015. Timing of unstructured transitions of control in automated driving. In 2015 IEEE Intelligent Vehicles Symposium (IV), 1167–1172.
10. Brian Mok, Mishel Johns, Key Jung Lee, David Miller, David Sirkin, Hillary Ive, and Wendy Ju. 2015. Emergency, Automation Off: Unstructured Transition Timing for Distracted Drivers of Automated Vehicles. In Intelligent Transportation Systems (ITSC), 2015 IEEE 18th International Conference on, 2458–2464.
11. Frederik Naujoks, Christoph Mai, and Alexandra Neukum. 2014. The effect of urgency of take-over requests during highly automated driving under distraction conditions. *Advances in Human Aspects of Transportation*, Part I: 431.
12. NHTSA. 2013. U.S. Department of Transportation Releases Policy on Automated Vehicle Development | National Highway Traffic Safety Administration (NHTSA). Retrieved August 6, 2014 from http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development
13. Jonas Radlmayr, Christian Gold, Lutz Lorenz, Mehdi Farid, and Klaus Bengler. 2014. How traffic situations and non-driving related tasks affect the take-over quality in highly automated driving. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2063–2067.
14. Joris C Verster and Thomas Roth. 2011. Standard operation procedures for conducting the on-the-road driving test, and measurement of the standard deviation of lateral position (SDLP). International Journal of General Medicine 4: 359–371.
15. Kathrin Zeeb, Axel Buchner, and Michael Schrauf. 2015. What determines the take-over time? An integrated model approach of driver take-over after automated driving. In *Accident Analysis & Prevention* 78: 212–221.
16. J2944: Operational Definitions of Driving Performance Measures and Statistics - SAE International. Retrieved September 18, 2016 from http://standards.sae.org/j2944_201506/