The Effect of Surrounding Scenery Complexity on the Transfer of Control Time in Highly Automated Driving

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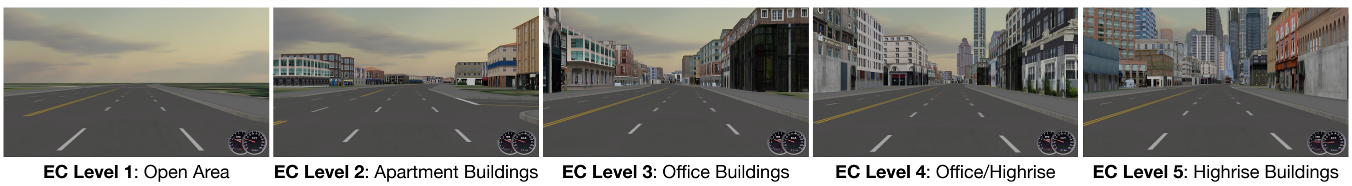

Figure 1: The five scenes of increasing environmental complexity used in the user study

ABSTRACT

One challenge in highly automated driving is the safe transfer of control (ToC). A safe ToC requires estimating the take-over time depending on the driver's state in different environmental conditions, to adapt the timing and design of the ToC request. We introduce environmental complexity as one factor that affects the ToC time. In a driving simulator experiment (N=12), the participants drove in five scenes having different environmental complexities (i.e. density and height of the background objects) with and without a secondary task. The results revealed that the ToC time is proportional to the environmental complexity. Thus, in the same driving task and the same traffic, an increasing environmental complexity yields higher ToC times in both conditions, with and without a secondary task. Our model of environmental complexity is a first step towards measuring the complexity of the real world, for a better prediction of ToC times in highly automated driving.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; *User studies.*

KEYWORDS

highly automated driving, transfer of control, driving simulator study, environmental complexity

ACM Reference Format:
Frederik Wiehr, Baris Cakar, Florian Daiber, and Antonio Krüger. 2021. The Effect of Surrounding Scenery Complexity on the Transfer of Control Time in Highly Automated Driving. In *26th International Conference on Intelligent User Interfaces (IUI '21), April 14–17, 2021, College Station, TX, USA.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3397481.3450677

1 INTRODUCTION

Highly automated driving (HAD, [1]) is about to hit public roads[1] and is currently approaching SAE level 3 [41]. Being able to perform a secondary task while driving, such as reading or using handheld devices, transforms vehicles into places for productivity and play [26].

The effects of automation on secondary task engagement [12, 44] and vice versa [10, 34, 36, 50] have been studied. However, a safe transfer of control (ToC) requires estimating the take-over time to adapt the timing and design of the ToC request. The question of what determines the take-over time is still central for HAD, and factors such as traffic density, action alternatives, interface implementation, type of secondary task, driver distraction and driver variables (e.g., age and skill of the driver) have been identified and modeled [9, 10]. Various studies have shown that it is very hard and sometimes impossible to transfer the control back to the driver in a very short period of time, not only in critical traffic situations [11, 18, 32], but also in non-critical situations [14]. Although effects of direct visual distraction have been studied as well [50], to the best of our knowledge, no studies exist that investigate the

[1]https://innovationatwork.ieee.org/new-level-3-autonomous-vehicles-hitting-the-road-in-2020/

IUI '21, April 14–17, 2021, College Station, TX, USA

ACM ISBN 978-1-4503-8017-1/21/04...$15.00
https://doi.org/10.1145/3397481.3450677

effect of the complexity of the static environmental background, independent of the traffic situation, on the take-over time.

However, we believe that optimal ToC time cannot be defined as a global value, since different environments might affect this time. In response to this problem, our study investigates the effect of different environmental complexities on the ToC time. In addition, we engaged the participants with a secondary task in order to be able to see a clear effect of environmental complexity after they took control of the vehicle again. In this respect, we introduce the environmental complexity as an additional factor that affects the ToC time, and conduct a simulator study to investigate if environmental complexity has a significant effect on ToC time during highly automated driving with and without a secondary task. This should enable designers of ToC interactions to better address the state of the driver when initiating a ToC in HAD.

2 RELATED WORK

Clearly, handovers also must be tailored to individual users and the take-over request must be adapted to driver readiness [31]. There has been extensive research on the design and timing of take-over requests [3–6, 25, 29, 33, 35, 40, 43, 46, 46] and trust in automation, e.g. on why people disable the autopilot, and effects of different visualizations [20, 44].

Situational awareness describes the human's awareness of the environment [13], including awareness of critical information for a task at hand, mainly known from aviation, but also applied to HAD [15, 40, 42]. Framework descriptions take the perspective of attention management [24] or provide an attention-aware architecture for the integration of handheld consumer devices, to increase the lead time for transitions and increase safety and comfort [48]. Secondary tasks cause negative effects on driving performance and situational awareness [2].

Factors influencing take-over time. ToC in critical situations has been examined in many studies [11, 18, 32]. A review of 25 studies on urgent take-over scenarios by Eriksson and Stanton [14] revealed that the mean allowed time for ToC was 6.37 ± 5.36 seconds and the mean reaction time was 2.96 ± 1.96 seconds. Mok et al. [32] examined driver behavior when drivers had to take over control before they encountered a road hazard. They tested three different transfer-of-control times, respectively 2, 5, and 8 seconds. Gold et al. [18] examined when a driver must engage with the driving task again so as to have safe handling in critical situations by comparing two take-over times, respectively 5 and 7 seconds, and also compared this to manual driving. The results showed that for a shorter ToC time, the reaction of the driver was faster and decision process was quicker. However, the quality of take-over was worse than it was given the longer ToC time. Following a similar approach, Dambök et al. [11] conducted a study which compared three different ToC times (4, 6 and 8 seconds). Their aim was to find the best case boundary where the driver would be able to handle even the most difficult case. During highly automated scenarios, the participants were completely distracted physically, visually and cognitively by a secondary task that had to be performed using both hands. This revealed that with the secondary task, the ToC time was shorter and the participants made more driving mistakes during the take-over. In contrast to the studies on ToC for critical take-over situations, Eriksson and Stanton [14] investigated ToC time in a non-critical scenario. They conducted a within-subject experiment with three different driving conditions (manual driving, highly automated driving and highly automated driving with a secondary task). The results showed an increase in take-over time if the transfer of control happened in non-critical scenarios.

In order to better prime drivers for the ToC, van der Heiden et al. [43] investigated auditory pre-alerts triggered well before the actual ToC request. However, it remains open how this ToC time can be estimated in relation to the time the human driver actually needs to regain control, i.e. the optimal ToC time. Merat et al. [29] found that drivers were able to regain stable control over the vehicle after around 40 seconds.

Other influencing factors on ToC time are driver distraction and secondary tasks in general, e.g. smartphone usage, which is known to affect traffic safety [7, 28, 45, 49]. Merat et al. [30] observed the worst ToC performance when the driver was engaged with a secondary task. Gold et al. [17] also found that participants reacted faster in manual mode than in automated driving mode. Pfleging et al. [34] explored various non-driving-related activities, e.g. daydreaming, writing text messages, browsing the web, and eating and drinking. Common secondary tasks that were used in studies are reading a magazine [14], watching a video [32], and interacting with a phone or tablet [18]. In their study on ToC in a non-critical scenario, Eriksson and Stanton [14] showed that there is a significant transfer of control time difference between highly automated driving with and without a secondary task. Traffic density is another factor that has a direct influence on the driver performance, both for manual driving and highly automated driving. Heenan et al. [21] investigated this effect for manual driving. Their study reveals that in high density-traffic, the driver's performance at controlling the vehicle speed decreases, as well as her situational awareness. Gold et al. [19] showed that traffic density in ToC scenarios led to longer take-over times and a worse take-over quality in the form of shorter time to collision and more collisions.

3 DEFINING ENVIRONMENTAL COMPLEXITY FOR HAD

After analyzing previous studies, especially regarding the factors influencing take-over time, we found no studies that investigated the effect of static variances such as changing environmental features around the vehicle on the ToC time. Consequently, we introduce environmental complexity as an additional factor that could affect ToC time in HAD.

Our definition of environmental complexity in HAD is based on two factors, namely saliency and number of objects (density). Saliency has been considered as a complexity measure for take-over before (e.g. [22]) and visual clutter is a known to affect driving performance [23, 27, 47]. We make use of the fact that an increased façade area also increases the saliency of an object [38]. The relevance of density, or more specifically the number of objects in the urban environment, is supported by the finding that increasing the number of objects along a road increases driver distraction [37]. Based on this, we define *environmental complexity* as follows: Environmental complexity (EC) is the density of the static non-traffic related structures (e.g. buildings) and their façade area around a highly automated vehicle (for synthesis of EC). Conversely, EC can be measured and aligned equidistantly by its saliency, masking out dynamic traffic-related objects (e.g. pedestrians and other cars) and applying the Feature Congestion (FC) measure and the Subband entropy (SE) to account for added visual saliency (for measuring EC) [39].

Based on this definition we designed five scenes of different environmental complexity, ranging from a basic scene that contains only the road network and no landmarks, up to a very complex level that is densely packed with high-rise buildings (see Figure 1). These levels are a sample set on a continuum of increasing environmental complexity, which we layered with the help of a pilot testing procedure.

4 USER STUDY

This driving simulator experiment investigates the effect of environmental complexity on ToC time in a HAD task. Previous studies mostly focused on the critical cases which force drivers to take over control of the highly automated vehicle. In our scenario, the reason why the car initiated the take-over request ahead of time is assumed to be that the provided map data was not sufficient in the approached region before a turn had to be taken.

Participants. Twelve participants (6 female, 6 male) between 23 and 31 years of age ($M = 26.25$, $SD = 2.563$) participated in the experiment. All participants had a valid driver's license and at least 2 years of driving experience. They all had normal or corrected-to-normal vision and no hearing impairment. None of the participants had prior experience with highly automated vehicles. Each participant ran through two training handovers with and without a secondary task.

Design & Hypotheses. A 2×5 factorial design was used within subjects, more specifically 2 driving tasks (with and without a secondary task) and 5 levels of environmental complexity. The transfer of control time was measured as the dependent variable. Environmental complexity and the secondary task were the independent variables.

If environmental complexity is related to take-over time, then the more complex the driving scene is, the more time the drivers should need to take over the control of the highly automated vehicle (H1). If having a secondary task is related to take-over time, then engaging the driver with a secondary task should increase the take-over time (H2).

Conditions. For the conditions, five different scenes with increasing *environmental complexity* were paired with a secondary task and without a secondary task (see Figure 1). We accompany this paper with a video that shows footage of all conditions and the study apparatus. Only the external non-traffic-related environment was changed. As a second condition, the participants were asked to drive the highly automated car with and without a secondary task, the tablet game *Vector Invaders* [16]. The environments used are as follows (see Figure 1):

EC Level 1: An open area scene was used as the least complex scene. It has a simple road network and surrounding green space. **EC Level 2**: An apartment building scene is an example of environmental complexity level 2. The road is surrounded by sparse apartment buildings. **EC Level 3**: An office building scene is an example of environmental complexity level 3. The road is surrounded by dense office buildings. **EC Level 4**: A scene of office buildings with skyscrapers represents environmental complexity level 4. The road is surrounded by dense office buildings and also two skyscrapers. **EC Level 5**: The high-rise building scene is the most complex among the five experimental scenes. The road is surrounded by many high-rise structures.

Task & Procedure. At the beginning of the study, the participants had to answer a questionnaire collecting demographics and checking for eligibility. Then they were briefed about the study procedure and informed consent was obtained as approved by the ethical review board. The participants were explicitly instructed to take over the control of the vehicle as quickly but also safely as possible, and that there was sufficient time available for the take-over. The simulated reason for take-over (insufficient map data available at the approached intersection) allowed for this, as the ToC was expected well in advance by the system.

The participants were asked to drive in five different driving scenes of different environmental complexity. The order of the scenes was randomized to avoid order effects with respect to the environmental complexity. Each scene contained two ToC requests, one with and one without a secondary task. The driving tasks for every scene started with autonomous driving. After $\tilde{6}0$ seconds from the start of the simulation in autonomous driving mode, the system initiated the ToC request with a beep on a straight road segment. The request was always triggered at the same position by an invisible box.

After the first ToC back to autonomous driving mode, the participant was asked to perform a secondary task until she received the second ToC request. Participants had to confirm that they were manually controlling the vehicle by pressing the paddle shifter buttons with both hands on the steering wheel, and received the verbal feedback "you now have manual control" after doing this.

Before the actual tasks, a warm-up scene was provided to allow the participants to get used to the controls of the driving simulator. Then the main experimental driving tasks started. After completing the tasks, the participants filled out a final questionnaire about their driving experience and trust in the system. Finally, the participants were asked to answer questions in a semi-structured interview regarding driving experience, trust and comfort.

Results. Each participant ran through two training handovers with and without the secondary task. *Influence of Environmental Complexity on ToC Time:* The results showed that when the driver is not engaged with any secondary task, it took on average 3.015s (SD=0.273s) in EC Level 1, 3.518s (SD=0.372s) in EC Level 2, 4.767s (SD=0.526s) in EC Level 3, 4.565s (SD=0.458s) in EC Level 4 and 4.939c (SD=0.724s) in EC Level 5 to take over control of the highly automated vehicle. The results also showed that when the driver is engaged with a secondary task, environmental complexity still influences take-over time. It took on average 7.674s (SD=0.394s) in EC Level 1, 7.606s (SD=0.539s) in EC Level 2, 8.762s (SD=0.577s) in EC Level 3, 9.608s (SD=0.691s) in EC Level 4 and 10.323s (SD=0.606s) in EC Level 5 to take over the control of the highly automated vehicle.

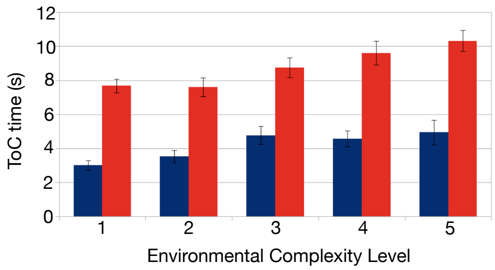

Figure 2: Take-over time vs. environmental complexity, without (blue) and with (red) the secondary task

Overall effect in the ANOVA for environmental complexity on take-over time was significant with $F(4, 44) = 9.985, p < 0.005$. The ANOVA showed that environmental complexity and take-over time are strongly correlated, but to understand clearly which levels are different and what the findings tell us, we calculated a linear trend to find out whether the take-over time increases linearly with increasing environmental complexity or not. The results show a linear trend for environmental complexity on take-over time with $F(1, 11) = 17.922, p < 0.005$ (see Figure 2).

The Influence of the Secondary Task on Take-over Time: The overall effect in the ANOVA for the secondary task on take-over time was significant with $F(1, 11) = 97.064, p < 0.001$ (see also Figure 2). When the driver is engaged with a secondary task before a ToC request, having her disengage from this task and take control of the car increased the take-over time approximately by a factor of $1.838 - 2.545$ compared to the take-over time without a secondary task.

A further result from the post-questionnaire was that the participants found the driving experience on our highly automated system very easy. The results also showed that average trust in the system was 46%, which shows that there was not complete trust in the system during transfer of control. Exactly half of the participants claimed they would use such a system if it were available on the market.

5 DISCUSSION

The results revealed that the ToC time is proportional to the environmental complexity. Thus, in the same driving task and the same traffic, increasing environmental complexity yields higher ToC times, with or without a secondary task. We also showed that engaging the driver with a secondary task increases ToC time considerably. Our findings can play a role in choosing a better timing for the take-over request for different environmental complexities in HAD.

One might expect that with a more complex environment, the driver would also increase their focus on the road, resulting in shorter ToC times even with a secondary task. Drivers who were visually distracted by an in-vehicle LCD screen looked at the road only 29% of the time, compared to 80% in the case of non-distracted drivers [45]. This visual time sharing is a possible explanation of the effects between our results for the secondary-task and non-secondary-task conditions. The environmental complexity, which only affects the background and the non-traffic-related situation, may not directly increase the criticality of the situation, and therefore may only add time for the driver to regain situational awareness during the take-over. To be able to perform a safe take-over process, the driver goes through the process of preparing for motor readiness, gazing at the street, cognitive processing and action selection, and finally reacting to the take-over request [50]. The expectation of seeing a faster take-over process in a more complex environment is therefore unlikely and would be rather unsafe, as some of these processes might not be completed.

When comparing the linear increase in the take-over times with and without the secondary task, the differences when the secondary task was included appear higher. This is an indication that the effects with the non-driving task engagement could be more severe at higher complexities.

It seems that an increasing complexity of the background non-traffic-related environment adds to the cognitive load for the driver. Another reason for increasing ToC time may be the fact that there is a psychological need for us to put ourselves into a spatial reference frame [8]. Increasing complexity also increases the time that is necessary to put ourselves into such a spatial reference frame.

The ToC times for tasks including a secondary task were higher than those without a secondary task (see Figure 2). This can be explained by the fact that a secondary task induces an additional mental workload. Furthermore, it forces the driver to focus on a task other than driving, or monitoring driving, and thus decreases situational awareness. The results confirm our second hypothesis (H2) and they are also in accordance with findings from prior work, e.g. [14].

6 CONCLUSION

In this work, we investigated environmental complexity as an additional factor affecting ToC time, which could support a better estimation of ToC times in highly automated driving by measuring the complexity of the real world. We also believe that when autonomous driving becomes an everyday reality, there will be new implications for our findings. The effect of environmental complexity may be also taken into account during this design of take-over interactions and choice of modalities. This will help create safe and well-designed take-over processes. In future work, we will further investigate environmental complexity and plan to test its effects in real-life driving scenarios.

ACKNOWLEDGMENTS

This work was partially funded by DFG grant 389792660 as part of TRR 248 (https://perspicuous-computing.science) and BMBF grant 01IW17004 (http://tractat.dfki.de).

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