An Online Study to Explore Trust in Highly Automated Vehicle in Non-Critical Automated Driving Scenarios

Conference Paper · September 2021

DOI: 10.1145/3473682.3480259

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ABSTRACT

While using highly automated systems, various non-critical automated driving scenarios can be identified in which trust plays a role. In this study, we investigated the change of trust in these scenarios with a digital "Feeling of Trust" indicator, through video-based online experiments simulating automated driving. Initial results show that trust even changes in these scenarios and revealed multiple influential factors. While trust seems to drop consistently in certain cases, we found individual differences in other events. With our experimental setup and findings, we provide a tool to examine trust aspects in an online study. This contributes to the understanding of how to design human-vehicle interactions in highly automated cars with the goal to calibrate trust under ordinary non-critical events.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); HCI design and evaluation methods.

KEYWORDS

Trust calibration, highly automated vehicles, video study

ACM Reference Format:
Haoyu, Dong, Bastian, Pfleging, and Marieke, Martens. 2021. An Online Study to Explore Trust in Highly Automated Vehicle in Non-Critical Automated Driving Scenarios. In *13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '21 Adjunct), September 09–14, 2021, Leeds, United Kingdom.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3473682.3480259

1 INTRODUCTION

Having the right level of trust plays an essential role in minimizing misuse and disuse of automated systems to create safe and enjoyable experiences [7]. Most of the current human factor research focuses on the level of trust in certain situations or on the take-over request. However, there is hardly any research investigating the entire process of maintaining an appropriate level of trust, especially in non-critical automated driving scenarios (NADS). We defined the NADS as the typical driving situations where the automated system conducts dynamic driving tasks without take-over requests, but drivers may still have trust issues. It is more common on a daily basis compared to safety-critical and emergent take-over request scenarios. Therefore, research on maintaining an appropriate level of trust in these scenarios is valuable for pushing the adoption of highly automated vehicles (HAV). Based on the concept of adopting different levels of automation for different situations and types of operation [6, 9], it is feasible to define dedicated areas (also called Operational Design Domain or ODD), such as highways. The automated system performs all dynamic driving tasks for a relatively long timespan and allows drivers to temporarily be out of the loop and conduct various non-driving related tasks (NDRTs) [8]. Currently, many studies regarding trust focus on full automation and how to increase trust [1, 10, 13, 14]. While in conditionally or highly automated driving (SAE L3, L4) [9], the most common research topic is the take-over request scenario [2, 3, 5]. However, design for trust calibration in the NADS requires more delicate considerations regarding people's mental model when they are allowed to conduct NDRTs, yet also need to be vigilant and situationally aware. On the one hand, this situation could be misperceived as full automation by the users, which leads to over-trusting. On the other hand, under-trusting could also refrain people from using the advantage of the higher automation function even within the ODD. Therefore, new types of human-vehicle interaction in HAVs need to be developed to calibrate trust in a way that supports conducting NDRTs and maintaining enjoyable user experience in a continuous manner in NADS. The fundamental question in our exploratory study is how people's situational trust changes in the NADS. We used a video-based online experiment to acquire initial knowledge of the context of NADS. Since situational trust is considered to be highly situation dependent and changing over time [4], we aimed at a continuous trust measurement to generate a continuous timeline of such changes and unearth the relevant influential factors.

2 THE EXPERIMENT

In this experiment, we presented five video clips to the participants including only ordinary driving scenarios, without particularly designated events that are expected to strongly decrease or increase trust. We created a digital tool for participants to annotate their feeling of trust while watching the videos. After each video, we conducted an interview while participants going through the video again and asked them to explain what influence their situational trust.

2.1 Participants

We recruited a total of 35 participants (17 female) for this study through social media and direct contact. The participants' age ranged between 18 and 60. Participants reported their current residence primarily in Europe (71.4%).

AutomotiveUI '21 Adjunct, September 09–14, 2021, Leeds, United Kingdom

ACM ISBN 978-1-4503-8641-8/21/09.
https://doi.org/10.1145/3473682.3480259

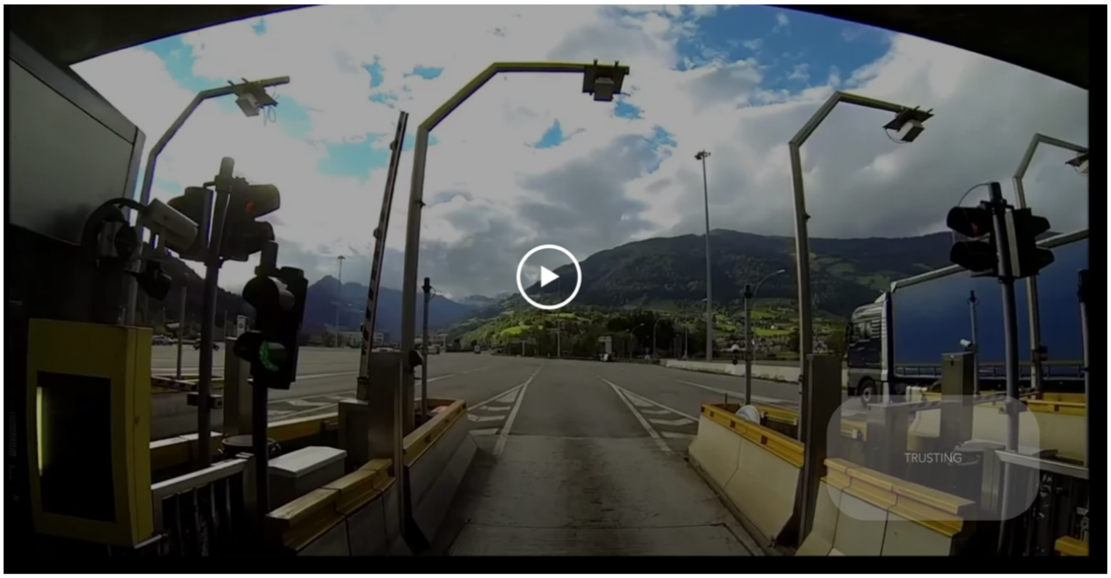

Figure 1: The translucent "Feeling of Trust" indicator locates at the right bottom corner of the video player (used with permission)

2.2 Video Selection

The video clips presented to the participants were trimmed from the pre-selected videos from YouTube (Appendix A). The videos show the driver's perspective in manual driving cars (SAE L0). In order to simulate automated driving, participants were informed that the videos were recorded with HAVs and they need to imagine themselves sitting in these cars. Each video clip included only normal driving events, such as overtaking and being overtaken, lane-changing, accelerating and decelerating, entering and exiting highway, following cars and driving in construction sites, etc.

2.3 "Feeling of Trust" Indicator

As the scenes continuously changed, it was important that the participants could respond fast and annotate their feelings of trust easily, without being too distracted and drawn out of the context while perceiving the ride. Therefore, we designed a digital indicator which was located at the right bottom corner of the video player (Figure 1). This indicator was inspired by the "Feeling of Safety" slider by Walker et al. [12] that measures people's willingness to cross in front of an automated vehicle in a real-time and continuous way. However, in this study, we only provided binary options: "Trusting" and "Not so Trusting". We focused more on the timeline of variation in the level of trust and phenomenological research. If the participants did not entirely trust their vehicles, they were instructed to hover the cursor over the indicator and the display of the indicator changes to "Not so Trusting" (Figure 2). Otherwise, they should keep the cursor away from the indicator[1].

Figure 2: "Feeling of Trust" indicator with activated "not so trusting" option

2.4 Methods and Procedures

A website was built for this online experiment. Before starting the experiment, the participants tried out the indicator. Then, they were presented with the videos one by one in a random order. After each video, a short interview was conducted. The experimenter went through the video together with the participants, while checking the timestamps labeled trusting or not trusting. We asked the participants to elaborate on what was happening in the video and explain their reasons for losing and regaining the trust. In this way, we allowed the participants to relive and reflect on their experience and map their thinking with the context [11]. After all five videos, they filled in a questionnaire for demographic data.

2.5 Data Collection

The data collection consisted of timestamps and recordings of the interview. The timestamps were organized into a CSV file and subsequently used to generate timeline visualizations for a more direct overview of all the annotations. Figure 3 depicts the visualization of Video IV[2]. The voice recording of the interviews were transcribed

[1]The screenshot is of Video I clip from: Robert Myrick Photography, 2013. Driving Through Alps From Vipiteno / Sterzing Italy To Sindelsdorf Germany. [video] Available at: <https://youtu.be/P47GIs3za00> [Accessed 9 May 2021].

[2]As an example, we provide Video IV clip 25:30-28:54 from: DrivE, 2020. Driving from Switzerland to Slovakia part 1 (24. October 2020) from Mittelhäusern to Lustenau AU. [video] Available at: <https://youtu.be/4wgZ8KtDKm8> [Accessed 9 May 2021].

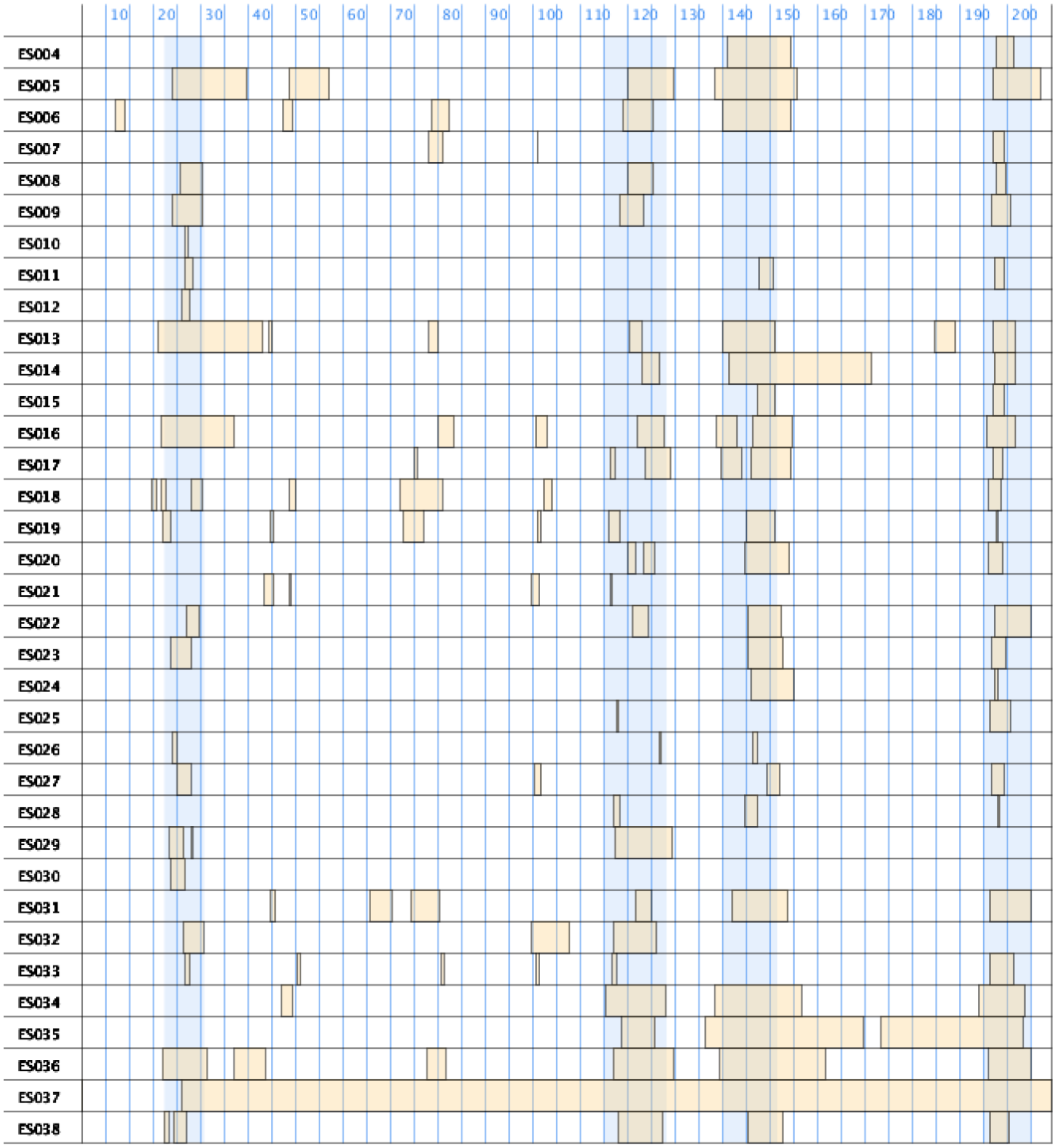

Figure 3: Timeline visualization of Video IV. Vertical axis is participant ID, horizontal axis represents the timeline of the video. The yellow blocks indicate "Not Trusting" periods. The blue strips show the segments on the timeline representing the events.

and coded into keywords. Based on the visualizations, we then tagged the segments on the timeline, where the majority of the participants annotated not trusting the vehicles (blue highlighted parts in Figure 3). Linking the timeline segments with the video clips and interview notes, we generated an integrated table for further analysis. In Table 1, we presented the events with the time, percentage of the "not-trusting" participants, descriptions, and subjective reactions.

3 PRELIMINARY RESULTS & DISCUSSION

Despite the limitations of online video-based study and potential lack of feelings of presence, our observations show that the level of trust still changes. We recognize that the participants were able to immerse themselves into the situations of the trip and reveal events in the presented video which caused (not)trusting the vehicles. Our preliminary analysis reveals common patterns of trust changes across most participants as well as individual reactions in

Table 1: Events in Video IV, with the time, percentage of the "not-trusting" participants, descriptions, and subjective reactions

Event (time, %)	Description of the event	Subjective reactions
1 (0:18-0:25, 58.8%)	Ego car enters construction site with temporary orange lines, another car moves forward close to the ego-car right before entering the tunnel.	The other car is getting too close (x11) Complicated road marks near construction site, not sure if my car can recognize it (x8) Entering a tunnel, poor vision (x7) Uncomfortable with the general maneuver of my car or the other car (x6)
2 (1:40-2:04, 67.6%)	Ego car drives on the left lane, the orange car indicating to merge in front of the ego-car to overtake one car on the right lane.	My car didn't slow down, it is getting too close (x17)
3 (2:15-2:26, 64.7%)	The same orange car indicates to merge in front of the ego-car to overtake two cars on the right lane.	The same situation happened again (x13)
4 (3:10-3:20, 76.5%)	The same orange car indicates to merge in front of the ego car with smaller margin. However, the ego-car doesn't compromise, and the orange car aborts the maneuver.	Expect my car to react better (speed up or slow down to get away from the car) or earlier (should have overtaken the car the second time) to the same car's erratic driving (x11) The orange car's behavior is confusing (x10) This aggressive behavior is dangerous of my car (x8) The behavior of my car changed (x7)

specific moments. Interestingly, in Video I, 13 out of 34 participants totally trusted the vehicle throughout the whole trip, while for Video IV, none of the participants trusted the vehicle during the whole trip. For Video IV, we were able to extract four salient events as shown in Figure 3 and Table 1. Overall, participants lost their trust regarding the same events at various time and for various timespan. In the selected videos, we purposely did not reduce the participants' trust or provide any type of interface to increase the trust. Yet the initial observation of the data shows that people's situational trust in NADS still fluctuates due to various reasons. For Video IV, there are inter-person differences regarding the onset and offset of (not)trusting the vehicle, but generally the participants were able to regain trust when they did not perceive additional risks after the events. For Event 1, not trusting the vehicle was related to different combinations of multiple factors, such as the close distance to another car, complicated road marks near a construction site, and poor vision due to entering a tunnel (as shown in Table 1). Future work is certainly required to clarify the differences and consistencies among participants, which could contribute to an adaptive interactive HMI in the future. For Event 2–4, the same orange car was involved, and it is interesting to observe that the subjective feedback of these events is actively linked to the other two. In Event 2 and 3, the ego-vehicle gave room for the orange car to merge into the lane, while it did not give the orange car the opportunity in Event 4. The participants recognized the change of behavior and compared it to the former events. Some participants approved the change of behavior of the ego-car and expected it to react better or earlier to the behavior of the other car. They also expected the ego-car to recognize the same car in all three events and adjust its maneuver considering this information. For trust calibration, it is important to investigate from a temporal and developmental perspective. When designing for in-vehicle interfaces, the influence of the vehicle's behaviors on trust with similar events should be considered to provide more smooth and natural riding experience. Our next step is to structurally analyze the data and categorize influential factors of trust change. This can be a starting point for proposing novel design concepts to bridge the gap for trust calibration in a continuous timeline. Future work could build trust models in NADS and investigate the exact overlap and differences between trust models in non-critical and critical situations. Furthermore, this provides a basis for conducting research in a more realistic setting in simulators or Wizard-of-Oz vehicles.

4 CONCLUSION

In the context of highly automated driving, it is consequential to maintain a proper level of trust in both emergent take-over request and non-safety-critical situations. This preliminary study aims at exploring the context of NADS with a video-based online setup. It underlines the continuous process of maintaining the appropriate level of trust and investigate the trust influential factors considering the evolvement of user's experience. The initial observation of the data shows the value and potential future directions of investigating the trust calibration in the NADS. Further work is needed to structurally present the results, which could contribute to the understanding the design requirements for human-HAV interactions in order to calibrate trust.

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A APPENDICES

The video used in this study.

Video Number	Time	Video Links
Video I	7:48-12:21	https://youtu.be/P47GIs3za00
Video II	25:23-29:46	https://youtu.be/jbhuWy1EEpc
Video III	2:05-5:00	https://youtu.be/GMtusG5tuC8
Video IV	25:30-28:54	https://youtu.be/4wgZ8KtDKm8
Video V	32:37-35:38	https://youtu.be/n7Rdp1WQsZk