# System Transparency: An Approach to Increase Trust in Automated Vehicles

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Position paper submitted to CHI 2018 workshop "Interacting with Autonomous Vehicles: Learning from other Domains" 

## Abstract
Plenty of work recently discussed problems such as trust in automated vehicles, acceptance of driving behavior/maneuvers, or management of takeover/handback requests. Given that all these systems increasingly operate on complex, even non-deterministic, algorithms, it is more and more likely for the driver-passenger, that he has no chance to get a comprehensive understanding of systems capabilities and drawbacks. To increase overall safety, road throughput or efficiency regarding travel time, it is also suggested to apply global optimization based on networking of vehicles, ITS and infrastructure (C2X communication). In order to maintain or increase trust in the system for the individual passenger, we propose to continuously present the system state (vehicle, object recognition in the surrounding, incoming messages) and explain the "why and how" of upcoming maneuvers. In this position paper, we introduce a few approaches and concepts to support system transparency and reflect its effect on driver trust.

## Author Keywords
Augmented Reality; Autonomous Driving; Windshield Displays; Human Factors; Trust.

## Introduction
Already today's automated driving (ADS) and advanced driver assistance systems (ADAS) face the problem of

**Study 1: Traffic Augmentation**

**Research Question:** Can augmenting traffic objects in the vehicle's vicinity help passengers to anticipate upcoming maneuvers and increase subjective trust?

**Method:** Participants faced multiple overtaking maneuvers in dense fog, with and without augmenting other vehicles (between-subjects design). After each condition, subjective measurements of trust (TAM/TS) were conducted.

**Results:** Augmentations led to significantly higher ratings in the evaluated scales, such as Trust, Perceived Usefulness, Perceived Ease of Use, and Attractiveness

wrongly calibrated user trust [7]. ADSs will become even more complex in the future and further may operate across multiple vehicles due to utilization of C2X communication and cooperative intelligent transportation systems (C-ITS). Future C-ITS applications are inspired by network control theory [4] and include intersection systems without traffic lights [1], switching directions on the same driving lane [5], or even driving with superhuman capabilities emerging from increased sensor range and C2X communication [8].

To support humans in such potentially ambiguous situations, new methods must be applied to foster trust in (and acceptance of) automated vehicles (AVs). A potential approach therefor is utilization of augmented reality technologies and windshield displays (WSDs) [8] to increase transparency by communicating system state and upcoming decisions to the user. Presenting "why and how" information to foster trust has successfully demonstrated in various studies [3], and can be achieved by both explicit (presenting upcoming maneuvers and system decisions) and implicit (sensor augmentation; the user sees "what the vehicle sees") communication. To investigate how such communication methods can contribute to a clear understanding of automated driving systems, we have conducted three user studies in potentially ambiguous future scenarios. In this paper, we present the different approaches and summarize our initial findings. We'd like to discuss our findings at the workshop and engage with and learn from other participants.

## Study 1: Traffic Augmentation in Superhuman Driving

Due to advances in sensor systems and C2X communication, future vehicles may be able to see details in the environment that are hidden for human eyes, and thus can drive faster than humans would. In our first experiment we have put passengers into a simulated environment where sight was hindered due to dense fog. Participants had to take a trip in a fully automated vehicle that performed multiple overtaking maneuvers. In a baseline condition, participants experienced this scenario without visual aids. To increase system transparency, we developed a system aiming to build a shared mental model that makes system intentions transparent to the user, without explicitly announcing overtaking maneuvers. Participants were presented augmentations of traffic objects via bounding boxes on a full-sized windshield display (see Figure 1). Driver-passengers could now see other vehicles even when hidden behind fog and thus anticipate upcoming overtaking maneuvers (**implicit feedback**). We conducted a user study (N=26) and assessed qualitative (trust scale TS, technology acceptance model TAM [6]) and quantitative (HRV) factors. Results indicate that augmenting sensor data in the driver's line of sight can indeed lead to increased trust and acceptance.

**Figure 1:** Augmenting traffic objects in the vicinity allows driver-passengers to anticipate upcoming driving maneuvers (*implicit feedback*).

**Study 2: Maneuver Augmentation**

**Research Question:** Can communicating upcoming maneuvers increase subjective trust when driver-passengers are not able to see what happens in front of the vehicle?

**Method:** Participants were presented a drive with a fully automated vehicle with their seat rotated facing backwards. Upcoming maneuvers (turns, stops, overtaking, etc.) were presented on a head-mounted display. Afterwards, subjective measurements of trust (TAM/TS) were conducted.

**Results:** Augmentation of upcoming maneuvers led to significantly higher ratings in multiple of the evaluated TAM/TS scales.

## Study 2: Maneuver Augmentation in Backward Driving

Another concept frequently addressed by future designs of automated vehicles are rotated drivers' seats. This could allow drivers to interact with others, or effectively work in office-like settings. However, due to the changed facing direction, driver-passengers cannot observe the environment ahead and thus must have deep trust in the vehicle to perform the driving task appropriate. To increase acceptance and trust, we presented upcoming maneuvers (**explicit feedback**) in form of symbols on a head-mounted display (Microsoft Hololens). Participants faced three different conditions in a randomized within-subjects design. In the baseline condition, no visual aids were presented. In the two experimental conditions, we presented upcoming maneuver symbols in either *perceived* (to fit the participants' perspective) or *logical* (to fit the vehicle's perspective, see Figure 2) direction.

**Figure 2:** Augmenting upcoming maneuvers when driver-passengers face backwards (*explicit feedback*). The vehicle driving a left turn presents the maneuver symbol in either perceived (left) or logical (right) direction.

Again we measured participants' subjective trust levels with standardized questionnaires (TAM, TS, Simulator Sickness Questionnaire SSQ) and further included pressure and accelerometer sensors to quantify how subjects prepared themselves to upcoming forces. Results show that maneuver augmentation leads to increased trust and acceptance, and that arrows in *perceived* direction were preferred over arrows pointing in *logical* viewing direction.

## Study 3: Temporal Preview at High Speed Intersections

In a third study we address future intersections managed by C-ITS systems. Here, multiple vehicles can enter the intersection at the same time and with high speeds. Driver-passengers experiencing such scenarios must trust these systems even more as due to the little distances to other vehicles a crash is "just around the corner".

**Figure 3:** When vehicles pass future intersections with high speed, a map preview from a birds-eye perspective may help users to understand system decisions.

To evaluate such situations, we implemented a highly immersive simulation in virtual reality where participants are facing 4 different intersections scenarios (see Figure 3). We hypothesize that experiencing these scenarios will reveal trust issues, and that augmentation again can assist driver-passengers. To increase system transparency and prepare users, we present a 3-second preview of the intersection scenario as planned by C-ITS from a birds-eye perspective. Participants can thus see how exactly paths are

**Study 3: Temporal Preview**

**Research Question:** Can presenting a temporal preview of upcoming situations increase users' trust in decisions of C-ITS applications?

**Method:** Participants experience multiple intersection scenarios where vehicles enter/pass with high speed. After each condition, subjective measurements of trust (TAM/TS) are collected.

**Results:** Study ongoing.

planned and vehicles will be controlled so that a safe passing is possible for all involved entities. Subjective trust will again be quantified using standardized scales (TAM, TS, Jian/Bisantz et al. [2]) and, in addition, physiological measurements (HRV, GSR) will be included. The experiment is ongoing and results will be published elsewhere.

## Conclusion

In this position statement we presented three experiments aiming to evaluate the potential of augmented reality technologies for fostering user acceptance/trust in fully automated vehicles and C-ITS applications. Initial results confirm our hypotheses, that both *implicit* and *explicit* communication of "why and how" information is able to increase system transparency and thus grant for a deeper understanding of automated driving/C-ITS technology. Study participants so far confirmed in semi-structured interviews that the loss of control resulting from driving automation was felt to be highly intense in ambiguous situations such as the ones evaluated. Of course some could argue that in a far future, where sophisticated C-ITS systems manage large numbers of fully automated vehicles, trust issues might not be relevant any more - similar as we today do not fear to board airplanes starting and landing in bad weather conditions using Autopilots. However, automated vehicles will pervade our streets gradually and the success of C-ITS is dependent on a high ratio - and thus high acceptance - of automated vehicles. Thinking of how we can support this process and persuade skeptics to enable/use automation will be essential during the next years.

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