# Automated Driving: Human-Factors Issues and Design Solutions

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# Automated Driving: Human-factors issues and design solutions

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The goal of this paper is to outline human-factors issues associated with automated driving, with a focus on car following. First, we review the challenges of having automated driving systems from a human-factors perspective. Next, we identify human-machine interaction needs for automated vehicles and propose some available solutions. Finally, we propose design requirements for Cooperative Adaptive Cruise Control.

## I. INTRODUCTION

Automation has entered many aspects of our daily life, including the way we transport ourselves. Adaptive Cruise Control (ACC), lane-keeping assistance, and blind spot assistance are being introduced into vehicles at a rapid pace. Such systems provide information and advice (e.g., warnings, suggested actions) or control the vehicle in specific longitudinal or lateral tasks. Although fully automated cars have been under investigation for about half a century (e.g., Levine & Athans, 1966; Burnham & Bekey, 1976; Ioannou & Chien, 1993; Hallé & Chaib-Draa, 2005; Naus et al., 2009), they are not yet available for public use. The challenges of vehicular automation are more than technical. Neale & Dingus (1998) stated that “the hardest problems associated with an Automated Highway System (AHS) … are ‘soft’; that is, they are human factors issues of safety, usability, and acceptance, as well as institutional issues. These are problems that are many times more difficult to overcome and must be overcome, largely, in parallel with the traditionally ‘hard’ technological issues” (p. 111).

## II. CHALLENGES OF INTERACTION BETWEEN HUMAN AND AUTOMATION

One might be inclined to think that automation eventually reduces the human’s task to the selection of the travel destination. However, the reality is that even with highly automated systems, the contribution of the human operator is crucial (Bainbridge, 1983). Using automation shifts the human’s driving tasks from manual control to supervisory control of the conducted maneuvers (Geyer et al., 2011). Being ‘out of the loop’ may lead to overreliance, behavioral adaptation, erratic mental workload, skill degradation, reduced situation awareness, and an inadequate mental model of automation capabilities (cf. Endsley & Kiris, 1995; Parasuraman et al., 2000). In the following, we briefly revisit these issues in the driving context.

### Overreliance

Overreliance (or complacency) is defined as the situation where the human does not question the performance of automation and insufficiently counterchecks the automation status. Distraction and poor judgment are two major causes of accidents (Peters & Peters, 2002). Overreliance and loss of vigilance could make these problems worse. For example, Kazi et al. (2007) found that drivers are not good in developing appropriate trust levels with respect to the reliability level of ACC.

### Behavioral Adaptation

Rajaonah et al. (2008) showed that drivers who often use ACC had a lower perceived risk and lower workload than infrequent users of the system. An experiment by Rudin-Brown & Parker (2004) showed that drivers using ACC may be more tempted to engage in activities other than driving. Drivers using ACC tend to adopt higher speeds and shorter headways than drivers without ACC (Hoedemaeker & Brookhuis, 1998), a phenomenon which can be explained by the risk homeostasis theory (RHT) (Ward, 2000; Wilde, 1988). The RHT states that humans adapt their behavior when their perceived risk changes, to restore their target level of preferred risk.

### Erratic Mental Workload

Automated systems have the potential to relieve the human of tasks that are complex, dangerous, or temporally demanding. Consequently, automation reduces mental workload in routine situations (e.g., Ma & Kaber, 2005; Stanton & Young, 2005). However, automation can also increase mental workload in unexpected situations (Vahidi & Eskandarian, 2003). Lee (2006) summarized several examples from the aviation and shipping industry where poorly designed automation results in an improper increase of workload.

### Skill Degradation

Loss of manual control skills due to automation is a serious concern in the highly automated aviation industries (Damos et al., 1999). Automation not only results in loss of psychomotor dexterity but also degradation of the cognitive skills required to accomplish the task successfully (e.g., Parasuraman et al., 2000).

### Reduced Situation Awareness

High levels of automation can prevent humans from receiving feedback within a proper time window, can diminish understanding of the process under control, and result in degraded event detection and response (Norman, 1990; Sarter

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& Woods, 1997; Young & Stanton, 2002; Wickens, 2008). An experimental study by Spiessl and Hussmann (2011) showed that compared to manual control of the steering wheel, operators of an automated steering system adopted longer reaction times. A related issue is carrying out inappropriate actions for the mode that the automation is in, a phenomenon known as mode error (Degani et al. 1999). Research has shown that lack of mode awareness can significantly increase the response time of the driver (Horiguchi et al., 2010). In a driving-simulator experiment, Stanton et al. (1997) showed that a third of the participants were unsuccessful in reclaiming control of the vehicle without collision.

### Inadequate Mental Model of Automation Functioning

Automation does not control the vehicle the same way as a human does. Because of sensory limitations and regulatory requirements, automation systems have a restricted working envelope (Zhang & McDonald, 2005). For example, although ACC systems can maintain steady headway and constant speed, radars used in ACC have a limited operating range. Drivers could fail to reclaim control of the vehicle due to not clearly understanding the ACC’s functional limitations (e.g., Stanton & Young, 2000).

## III. Main Interaction Functions of Human and Automated Car

Because of vehicular automation, humans are more engaged in supervision and intervention and less involved in manual control and continuous compensation of the vehicle (Sheridan, 1999). With ACC, humans are currently required to handle new tasks including initialization (e.g., headway setting), monitoring automation status, and takeover control (e.g., when approaching a sharp curve). Humans need to interact with the automation system for two main functions (adapted from Ran et al., 1997): (a) authority transitions, (b) human-vehicle instruction and feedback. In the following, we explain these functions.

### Authority Transition

Authority transition is defined as the timing and procedure of transferring responsibility from the human to automation system, and vice versa. Some situations requiring a transition are automation failure, road blockage, severe weather conditions, sudden maneuvers by another vehicle, and operator preference. A proper automation system should avoid automation surprises, and facilitate proper trust on automation (Adell et al., 2011). The human should be aware of the automation system’s limits well in time and be able to take over the vehicle control when needed (Pauwelussen & Feenstra, 2011).

### Human-to-Vehicle Instruction and Vehicle-to-Human Feedback

Not only the presence of the feedback is important, but feedback should also be provided in a timely and useful manner. Humans may miss nonsalient warnings, whereas too salient warnings are annoying (Lee et al., 2007). Feedback provided too early or inappropriately (i.e., false alarms) can result in distraction, ignoring the alarm, or shutting down the alarm system entirely (Meyer & Bitan, 2002; Parasuraman & Riley, 1997). Abe & Richardson (2005) showed that drivers trust early collision alarms more than late alarms.

Displays and automation settings may need to be configurable based on operator preference. Setting customization, however, can be a double-edged sword because of potential confusion by other users.

## IV. Potential Solutions for Interaction of Human and Automation

The driver and vehicle automation interaction mechanism deals with achieving the functions and purposes addressed above. In the following, we present some available solution frameworks.

### Shared Control

Several researchers have argued that interactions between human and automation should not merely consist of activations and deactivations. They have proposed developing appropriate frameworks to keep drivers involved in the control loop (Stanton & Young, 2000), allow drivers to understand the system’s capability (Seppelt & Lee, 2007), and support the acquisition of situation awareness with a minimum of cognitive effort.

Shared control is a framework whereby human and automation cooperate to achieve the required control action together. This approach should realize automation benefits (e.g., fast response, accurate control) while avoiding problems such as the out-of-the-loop unfamiliarity and mode errors (Flemisch et al., 2012). Abbink et al. (2012) developed a haptic gas pedal and steering which has been tested as a medium for shared control for car following and curve negotiation. The gas pedal stiffness adapts according to the headway to the following car. The human can still overrule and change the distance by using more or less force on the pedals. De Winter and Dodou (2011) provided a critical reflection of the literature on the effects of shared control on road safety. They argued that force feedback should not be provided continuously, but only when deviations from acceptable tolerance limits arise.

### Adaptive Automation

Variation in driving conditions (e.g., infrastructure, traffic rules, traffic density, and weather) and drivers’ population (e.g., age, gender, and experience) justify designing automation systems that can adapt to these differences. Adaptive interfaces can reduce the driver’s mental workload by filtering the presentation of information according to situational requirements. Piechulla et al. (2003) implemented such a filter as a projective real-time workload estimator based on an assessment of the current traffic situation. In a driving-simulator study, Lee et al. (2007) quantified driver sensitivity to different ranges of brake duration and magnitude. They suggested that their findings could be used to create ACC algorithms and develop brake pulse warnings. Adaptive automation can also be used to monitor and alert drivers to their impairments, such as drowsiness and inattentiveness (Victor, 2000).

### Use of an Information Portal

Providing the relevant information at the suitable moment can assist drivers to improve their situation awareness (Seppelt & Lee, 2007; Stanton & Young, 2000). An information portal can be used to communicate required actions, provide augmented feedback (e.g., improved rear-view vision or enhanced night vision), provide recommendations for better performance (e.g., eco-driving feedback), or to highlight risky driving conditions (e.g., blind spot assistance). In automated systems, information portals can be used to avoid automation surprises and increase the acceptance rate of the system. Information portals can be implemented as visual displays, or by complementing thvisual task-intrinsic information with non-visual (audio) cues (e.g., Van Den Broek et al., 2010; Risto & Martens, 2011).

### New Training Methods

Because the role of the human changes from manual to supervisory control, changes in driving licensing and driver training may be needed. Future drivers may have to demonstrate competency in computer skills and mode-conflict resolution, while psychomotor skills will be less relevant. Educating drivers on the capabilities and limits of automation has been proposed as a preventive strategy to minimize adverse behavioral adaptation (Stanton & Young 2005; Rudin-Brown & Parker, 2004).

Automation can be used to develop new types of training. In theory, a consistent, accurate, and tireless automated trainer is capable of capturing every event in the vehicle, including erratic and unsatisfactory human behavior. Sensor systems can reveal transient errors or driver drowsiness, which might remain unnoticed by human trainers. Using automated trainers can result in a quantitative evaluation of the operator, making it possible to provide feedback of human error in real-time (e.g., Panou et al., 2010).

## V. Requirements and Potential Solutions of Human Interaction with CACC

We propose using the Cooperative Adaptive Cruise Control (CACC) system as a main platform to integrate human-automation control. The CACC system enables a platoon of two or more vehicles driving with automated longitudinal control at a set distance parameter (e.g., time headway) through shared kinematic information (Naus et al., 2009). Cooperative cars can be used in driving in reduced visibility, such as in fog, at night or on unlit motorways, and for driving long periods. In these conditions, cooperative vehicles have the potential to outperform humans in terms of safety, traffic flow, and eco-driving. In the CACC framework, one can distinguish three main maneuvers: platooning, joining, and splitting. Joining and splitting are transition maneuvers, whereas platooning involves stationary motion.

In the following, we discuss design requirements, expected human-factors issues, and design solutions for interaction between drivers and CACC. These findings are based on the human-factors issues discussed in Section II, the CACC goals and functions briefly introduced above, and a consideration of the main interaction functions in Section III.

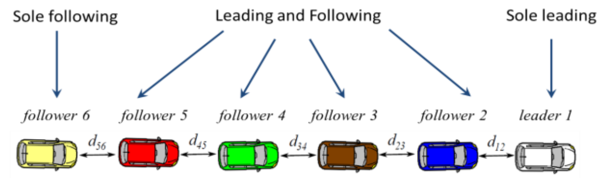


Figure 1. Illustration of CACC-equipped platooning vehicles.

### CACC Design Requirements

We assume that all vehicles are equipped with equivalent CACC systems. Thus, the issue of interaction with heterogeneous technologies is not considered.

*System Initialization*. The system should make drivers aware whether the CACC is enabled or disabled. Initialization should result in a clear driver understanding of what the headway and speed setting implies in terms of stopping distance and hazard. The system should enable drivers to distinguish the difference between driving in platoons and individual driving. The system should enable drivers to easily retrieve and change the headway and speed settings, and the initialization setting should not pose too much extra workload on drivers (i.e., no erratic mental workload).

*Platooning*. The tailgating behavior of CACC cars should gain acceptance of drivers. Drivers should not experience automation surprises, such as very rapid acceleration and deceleration, sudden closure of inter-vehicle gap, unexpected change of the topology of the platoon, and poor string stability. The system should clarify and communicate the constraints that driving in platoons pose in terms of feasible maneuvers (i.e., have a correct mental model). For example, the system should make it clear for drivers that they are not able to override the headway instantly. Drivers should have an option to come out of the platoon in a safe and smooth manner (i.e., proper trust) and should not experience very low workload levels.

*Joining and Splitting* can be initiated either by platoon control hierarchy (Hallé & Chaib-Draa, 2005) or by the human. Drivers should be able to take over vehicle control when coming out of the platoon. Drivers should not be surprised by the automation's behavior, either initiated by the controller or driver. Joining and splitting should be performed with as few as possible steps to avoid confusion (i.e., avoid mental overload). The system should make drivers aware of the start, end, and the process of the joining and splitting transitions.

### CACC Design Solutions

*Initialization*. The process of selecting a headway and speed during driving is distracting and disconnects the driver from the driving task. In addition, there is a risk that the driver does not fully understand what the setting implies. The use of additional icons can be distracting, while the learning and remembering involved can impose an extra workload on drivers. An alternative option is to use a system consisting of an adaptive setting based on the driver's history of manual car following. The system can choose the average minimum headway distance and maximum speed that the driver held for more than a set period (e.g., one minute) within the most recent hour of driving. Such a mechanism will prevent the driver from having to face an unexpected following distance and bring forward an expected following distance. The CACC should be turned on by the driver who should be informed of the system status by visual/audio cues to maintain correct awareness.

*Joining*. When the system is on, the car should start cruising at the set speed, resort to car following when approaching a slower vehicle, and brake to a complete standstill if needed. In other words, a platoon can be joined from the rear without driver intervention. However, drivers have to be informed about large speed differences, and may be advised to change lanes to better follow their desired speed. Here, adaptive automation may be used, monitoring the driver state, and providing person-specific advice to the driver. Drivers should be aware of situations where joining is not feasible due to the maneuvers of other members of the platoon or any other constraints, such as maximum length of the platoon because of the road layout. Thus, transitions in the platoon that pose constraints on any other platooning members should be communicated to the constrained members.

*Platooning*. The state of the system should be clearly communicated to the driver as "Platoon Mode" through a communication portal or icon. This mode can be announced audibly and repeated at certain intervals to keep the human aware. Again, using adaptive automation, frequency, and intensity should be raised when humans are potentially less attentive (e.g., when they do not provide any input for a prolonged time).

When platooning, humans should not experience unannounced or abrupt changes. Topology changes in the platoon and the splitting off and joining of other members should be announced to avoid surprises and lowering of trust in the automation. Humans should be aware of the limits of maneuvers. For example, a human cannot close the headway beyond a certain threshold and should not steer instantly. To avoid sudden steering, haptic feedback can be used on the steering wheel.

*Splitting*. Drivers should be able to safely end their platooning. One potential solution is that the human increases the headway to an allowable limit. When this limit is reached the CACC system disables and the driver is informed of the shutdown via an information portal.

## VI. Conclusion

This paper reviewed several human-factors challenges of automated driving. We applied the issues, needs and solutions for vehicle automation to the concept of CACC and proposed an interaction mechanism between humans and CACC. The proposed system has few modes, keeps drivers engaged in the control loop, and facilitates cooperation between drivers and their vehicles as well as among other vehicles.

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