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## Consumer Use & Adoption of Advanced Vehicle Systems

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## Project Overview and Key Findings

Vehicles equipped with assistance automation systems are conceived to perform the entire dynamic driving task while engaged, with the exception that the driver is expected to remain receptive to requests to intervene as well as to any performance-relevant system failures, and to respond appropriately to both (SAE J3016 Levels 1-3, 2018). This expectation for drivers to remain in a state of readiness despite uncertainty as to when or if they will encounter either a request to intervene or a system failure (here referencing a decrement in system performance or missed event due to sensor limitations) has raised concern over drivers being “out-of-the-loop” (Seppelt & Victor, 2016). In both simulation and on-road testing, drivers have shown difficulty resuming manual control in situations in which they have been removed from active control of the vehicle and have received a request to intervene (e.g., de Winter et al., 2014; Merat et al., 2014; Eriksson et al., 2017). Findings on the challenges drivers experience in being able to initiate timely and safe intervention responses when “out-of-the-loop” call for the need to develop novel interfaces that help drivers to maintain appropriate expectations of the vehicle’s capabilities and response behavior relative to the dynamics of the situation. A human-centered design approach was proposed to examine potential solutions to the challenge of keeping drivers sufficiently situationally-aware during use of assistive features to be able to safely and effectively perform an infrequent handover task. This approach was organized under a set of four tasks:

- Task 1: Literature review to define “out-of-the-loop” driver behavior
- Task 2: Literature review to define information requirements for assistance automation systems
- Task 3: Naturalistic data review to identify use cases of misaligned driver expectation of system behavior
- Task 4: Develop conceptual intervention human-machine interface (HMI) designs and/or design recommendations to support accurate driver expectations of system behavior

The overall aim of this research is to design safer assistance automation systems that keep the driver informed and involved in the driving task. The recent publications of *“The “out-of-the-loop” concept in automated driving: Proposed definition, measures and implications”* and *“Keeping the driver in the loop: Dynamic feedback to support appropriate use of imperfect vehicle control automation”* together defined what it means for a driver to be “in-” versus “out-of-the-loop” as well as the information requirements to support drivers in understanding and more appropriately relying on assistive features (Merat et al., 2019; Seppelt & Lee, 2019).

Analysis of a nationally-deployed survey on driver perceptions of AVs and of interview data collected from a four-week field operational trial (FOT), both from data initially collected within the AVT project (<http://agelab.mit.edu/avt>), revealed important information related to naturalistic system use of automated technologies

that informs the design of safer, more effective HMIs. Some key findings were as follows:

- Survey responses from 3819 adults in the United States indicated that the general public have misunderstandings regarding the state of vehicle automation technology, which points to a basic misperception of the definition of self-driving. Specifically, when asked to define “self-driving” automation, responses were divided across different options that paraphrase SAE J3016 (2018) levels of automation, with close to half (46.3%) of participants believing that “self-driving” requires driver involvement to some degree. The set of survey responses indicate inconsistencies and misunderstandings in general consumer knowledge and awareness of vehicle automation technologies.
- An interview analysis of twenty-four drivers (16 male, 8 female) who participated in a four-week field operational trial explored and documented perceptions of two unique lane centering systems (S90’s Pilot Assist, and CT6’s Super Cruise). Both systems offer similar functionality on paper (continuous longitudinal and lateral vehicle control), but have drastically different HMI implementations. While functionally similar, the two lane centering systems studied (Pilot Assist and Super Cruise) were perceived quite differently by participants. Results suggest that drivers’ comprehension and expectation of these systems’ behavior are strongly influenced by their HMI design, specifically in terms of their difference in hands-on versus hands-off-wheel implementation. The perceived role of the driver – as either a fallback driver or as the sole driver - may be influenced by this HMI design implementation. It is important to highlight the consequences of different design implementations for lane centering systems in order to provide guidelines for future HMIs and to better match designer with driver expectations.

### **Task 1 – Literature review to define “out-of-the-loop” driver behavior**

Reference: Merat, N., Seppelt, B., Louw, T., Engström, J., Lee, J. D., Johansson, E., ... & McGehee, D. (2019). The “out-of-the-loop” concept in automated driving: Proposed definition, measures and implications. *Cognition, Technology & Work*, 21(1), 87-98.

Link: <https://link.springer.com/article/10.1007/s10111-018-0525-8>

**Abstract:** Despite an abundant use of the term “Out of the loop” (OOTL) in the context of automated driving and human factors research, there is currently a lack of consensus on its precise definition, how it can be measured, and the practical implications of being in or out of the loop during automated driving. The main objective of this paper is to consider the above issues, with the goal of achieving a shared understanding of the OOTL concept between academics and practitioners. To this end, the paper reviews existing definitions of OOTL and outlines a set of

concepts, which, based on the human factors and driver behaviour literature, could serve as the basis for a commonly-agreed definition. Following a series of working group meetings between representatives from academia, research institutions and industrial partners across Europe, North America, and Japan, we suggest a precise definition of being in, out, and on the loop in the driving context. These definitions are linked directly to whether or not the driver is in physical control of the vehicle, and also the degree of situation monitoring required and afforded by the driver. A consideration of how this definition can be operationalized and measured in empirical studies is then provided, and the paper concludes with a short overview of the implications of this definition for the development of automated driving functions.

## **Task 2 – Literature review to define information requirements for assistance automation systems**

Reference: Seppelt, B. D., & Lee, J. D. (2019). Keeping the driver in the loop: Dynamic feedback to support appropriate use of imperfect vehicle control automation. *International Journal of Human-Computer Studies*, 125, 66-80.

Link: <https://www.sciencedirect.com/science/article/pii/S1071581918301277>

**Abstract:** This study evaluates the benefits and costs associated with providing drivers continuous feedback on the limits and behavior of imperfect vehicle control automation. In-vehicle automated systems remove drivers from active vehicle control, often at the expense of timely interventions when failures occur. Discrete warnings, as a type of feedback to inform drivers about automated system behavior, fail to keep drivers aware of its proximity to operating limits. In a fixed-based simulator, 48 drivers drove using Adaptive Cruise Control (ACC)—a form of control automation that maintains a set speed, or a set headway if the vehicle encounters a slower moving vehicle. A first experiment compared ACC with discrete warnings to ACC with continuous information, which indicated moment-to-moment ACC state relative to its operating limits. Three display conditions, designed to provide nonobtrusive, ecologically-valid information, were evaluated in a second experiment: 1) a visual interface; 2) an auditory interface; and 3) a combined visual-auditory interface. Drivers provided with continuous feedback relied more appropriately on ACC than did those with discrete warnings. Continuous feedback increased the frequency of proactive responses to automation failures and improved system understanding. Of the three displays, the combined visual-auditory interface performed the best. Continuous feedback helped communicate to drivers the evolving relationship between system performance and operating limits. Displays for increasingly automated vehicles should inform about the automation's situation-specific behavior rather than simply alert drivers to failures and/or the need to resume vehicle control in order to promote appropriate understanding and trust

### **Task 3 – Naturalistic data review to identify use cases of misaligned driver expectation of system behavior**

Reference: Seppelt, B., Lee, C., Russo, L., Reimer, B., Mehler, B., Fisher, J., Funkhouser, K., & Coughlin, J. (Abstract accepted). Consumer confusion with vehicle automation: What is a self-driving vehicle? SAE World Congress, 2020.

**Abstract:** A key human-related issue within vehicle automation concerns the degree of human engagement required to maintain safe control, either as an operator, monitor, supervisor, or passenger. To act appropriately in these roles, the human must have a clear understanding of his/her driving task responsibilities. These responsibilities change based on the type of automation engaged. Recent research indicates that consumers are often confused about the capabilities of deployed forms of vehicle automation due to role confusion, in which they assign greater role responsibility to these technologies than is intended by their design. This study explores effects of demographics and of experiences with technology in currently-owned vehicles on understanding and acceptance of vehicle automation. Survey responses from 3819 adults in the United States indicate that the general public may have misunderstandings regarding the state of vehicle automation technology, and point to a basic misperception on the definition of self-driving. Specifically, when asked to define “self-driving” automation, responses were divided across different options that paraphrase SAE J3016 (2018) levels of automation, with close to half (46.3%) of participants believing that “self-driving” requires driver involvement to some degree. The set of survey responses indicate inconsistencies and misunderstandings in general consumer knowledge and awareness of vehicle automation technologies.

### **Task 4 – Develop conceptual intervention human-machine interface (HMI) designs and/or design recommendations to support accurate driver expectations of system behavior**

Reference: Landry, S., Seppelt, B., Russo, L., Reimer, B., & Mehler, B. (Abstract accepted). Perceptions of two unique lane centering systems: An FOT interview analysis. SAE World Congress, 2020.

**Abstract:** The goal of this interview analysis was to explore and document the perceptions of participants in a field operational test (FOT), including two unique lane centering systems (S90’s Pilot Assist, and CT6’s Super Cruise). Both systems offer similar functionality on paper (continuous longitudinal and lateral vehicle control), but have drastically different HMI implementations. Twenty-four drivers (16 male, 8 female) in the Greater-Boston Area participated in an FOT study, in which each participant drove one of two vehicles for a month. Upon vehicle return, drivers took part in a 30 to 60-minute semi-structured interview to record their perceptions of the vehicle’s various ADAS systems. Transcripts of the interviews were coded by two researchers to assign each participant’s statements to specific vehicle technologies as well as to attribute perceptions to each statement. The

analyses in this paper focus on adaptive cruise control (ACC) and lane centering technologies. Participants cite perceived positive benefits, such as increased safety and comfort provided by lane centering and adaptive cruise control systems, but also cite concern over the possibility of increased inattention to the driving task. Driver perceptions of adaptive cruise control were similar between vehicles. When comparing perceptions of lane centering between vehicles, however, there were distinct differences. The proportion of drivers that cited benefits associated with comfort (enjoyment, reduced stress, increased comfort) was larger for those who experienced Super Cruise (a hands-off-wheel system) than for those who experienced Pilot Assist (a hands-on-wheel system). However, the proportion of drivers that cited a redundant safety benefit provided from the use of lane centering was larger for those who experienced Pilot Assist than for those who experienced Super Cruise. Overall, perceptions of drivers who used Pilot Assist indicate they were more likely to view the system's role as back-up for the human driver, whereas those for drivers who used Super Cruise were more likely to view their role as back-up for the system. While functionally similar, the two lane centering systems studied (Pilot Assist and Super Cruise) were perceived quite differently by participants. Results suggest that drivers' comprehension and expectation of these systems' behavior are strongly influenced by their HMI design, specifically in terms of their difference in hands-on versus hands-off-wheel implementation. The perceived role of the driver – as either a fallback driver or as the sole driver – may be influenced by this HMI design implementation. It is important to highlight the consequences of different design implementations for lane centering systems in order to provide guidelines for future HMIs and to better match designer with driver expectations.

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