EXCHANGES OF AUTHORITY IN AUTOMATED VEHICLES: DISPLAY NEEDS FOR HANDOVER AND TAKEOVER REQUESTS

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ABSTRACT

As automation is introduced in vehicles, authority for control of essential vehicle functions may be transferred between the human driver and the automated components of the system. These exchanges of authority will require well-designed displays to keep the human driver informed of the status of automated systems and the delegation of moment-to-moment control responsibilities. In this comment, I identify a timeline of hypothetical events in the exchange of authority between human drivers and automated systems that may help to identify research needs in the development of context-appropriate displays, including auditory displays for handover and takeover scenarios in vehicles with automation.

1. INTRODUCTION

The Society of Automotive Engineers' (SAE) taxonomy of automation in driving [1] describes six levels of vehicle automation. At SAE Levels 1-3 (and possibly at Level 4), authority for control of one or more dynamic driving tasks (DDTs)—including lateral and longitudinal vehicle control, monitoring, and executing appropriate responses to events—is shared between the driver and the automated components of the vehicle. Most experts seem to believe that Level 5 automation will not be tenable for some time (e.g., [2]), thus shared authority will be an element of automated vehicle systems in the near term and possibly for many years to come. Shared authority between humans and vehicles in driving presents new challenges for the design of effective human-machine interfaces. Vehicle interfaces must be designed to allow for safe and effective transfers of authority.

2. ANATOMY OF EXCHANGES OF AUTHORITY

Exchanges of authority for control of DDTs are characterized by a series of events that require cooperation between the human driver and automated systems. Figure 1 presents a hypothetical timeline of the events that might occur in one full cycle of exchanges of authority from manual driving to a period of automated driving, then back to human control. The timeline is hypothetical in that the implementation of exchanges of authority in a given system will depend upon the capabilities and design of the system; not all events in this hypothetical timeline will necessarily apply to all systems. For the purposes of this discussion, the timeline is meant to generally describe exchanges of authority between the human driver and automated systems; the actual DDTs encompassed in the "automated driving" phase of the timeline could involve partial, conditional, and possibly high automation as described in the SAE standards.

The SAE descriptions of most levels of automation (i.e., Levels 1-3, and possibly Level 4) seem to imply that most drives will begin with the human in manual control of all DDTs. At some point in the drive, the conditions become appropriate for automation to be used, at which point a *handover request* (HOR) is issued. The HOR is an appeal for the automated systems to assume responsibility for one or more DDTs. In the near term, HORs likely will be initiated by the human driver, but the system could also be designed such that the vehicle requests permission to assume control of DDTs when it detects appropriate conditions. The system also could be designed such that the recipient of the HOR must acknowledge that the request has been received. The time between the initiation of an HOR and its acknowledgment could be characterized as a handover lag (a parallel to the *interruption lag* in the interruptions literature, see [3].)

After the HOR is accepted, a period of transition of control begins. After this transitional period, the handover is complete and the vehicle enters a period of automated control of one or more DDTs. The duration of the handover lag and the transitional period will depend on the design of the system. One can imagine a system in which the press of a button accomplishes the HOR, its acceptance, and the handover—a design that effectively makes the handover lag and transition durations zero—much like with traditional cruise control, for example. Yet even this straightforward design arguably entails a transitional phase during which the driver monitors the system for feedback to ensure that the automated function has engaged. With more advanced automation, human factors and other considerations may warrant designs that rely on more gradual transitions. During these transitions, feedback about responsibility for DDTs will be imperative.

During a period of automated driving, either the driver or the automated systems may issue a *takeover request* (TOR)—an appeal for the human driver to retake manual control of DDTs from automated systems. A TOR could be issued by the human or by the automated components of the system (see [4]). The human might observe potential problems with automated systems and desire to take control, or she or he may wish to assume control for reasons unrelated to the performance of automated components. The automated systems may issue a TOR to the human if they encounter difficulties or if a change in driving mode is imminent (e.g., a transition from highway to street driving). The time between a TOR and its acceptance or acknowledgment could be described as a *takeover lag*. After the TOR is accepted, a transition period begins, during which the primary goal should be to ensure that the human driver has reoriented to the driving task following the period of

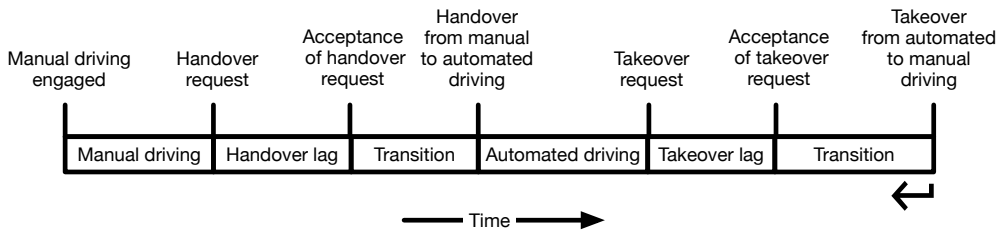

Figure 1. Hypothetical timeline of exchanges of authority between human drivers and vehicle automation. Relative durations shown are arbitrary. See text for discussion.

automation, which may have involved distraction by non-driving secondary tasks. Following the transition period, takeover is complete and all DDTs are the responsibility of the human. The duration of the takeover lag for a machine-initiated TOR will depend upon the response time of the human. The duration of the lag for a human-initiated TOR will depend upon the response time of the automated systems.

It is important to note that human factors experts have expressed deep concern regarding the ability and/or willingness of human drivers to be prepared to intervene without a sufficient transition time [5]. The time necessary to re-establish situation awareness after attention has been directed away from the driving task has not been established. Some research has suggested adequate human takeover performance with lead times of a few seconds (e.g., [6]), while other research has suggested that baseline manual driving behaviors take much longer to re-establish after a period of vehicle automation (e.g., [7]).

3. DISPLAY NEEDS

Exchanges of authority will entail a cooperative effort between the human driver and the automated components of the system. Sharing of authority will require the development of displays that provide effective feedback to the human driver about the status of the automated systems. The timeline in Figure 1 offers an outline of the events in the exchange of authority that likely will require displays to keep the driver apprised of the status of automated driving tasks. Most of these displays will involve a visual component (i.e., a visual information display will be part of the system). Notably, however, every event in the timeline will potentially place multiple demands on the driver's visual attention. During all transitions from manual to automated driving, the driver will need to monitor the road until she or he is confident that the handover has been successfully completed. Auditory or haptic displays may allow the driver to focus on the road instead of seeking feedback from visual displays during the handover to automated driving.

During periods of automated driving, evidence suggests that drivers will engage in secondary tasks, which often will involve visual distractions (e.g., [8], [9]), so auditory or haptic displays may be needed to ensure that takeover requests are perceived. Auditory and haptic displays may also be able to facilitate effective takeover transitions; drivers could listen to status updates regarding the withdrawal of automated control of DDTs while simultaneously regaining visual awareness of the driving scenario. Although researchers have begun to explore how to design multimodal displays to facilitate handovers and takeovers (e.g., [10]), the design of displays to facilitate safe exchanges of authority is a pressing issue in vehicle automation.

4. REFERENCES

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