Toward Integrated Automation Status and Alerting Display Management Systems for Vehicles

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Abstract. With increasing levels of automation on modern vehicles, drivers need more knowledge about their vehicle than ever before. Thereby, the display of vehicle status and alerts are important means for safe and effective use. Nevertheless, there are currently no common and consistent ways of providing such status in-formation to drivers. This is different from other domains where standardized alert management structure are common such as in modern aviation. In current vehicles, initiation, use, and termination of automated driving assistance differs considerably between vehicle models and brands and require special learning ex-periences by the driver and alerts are not prioritized and harmonized across the various onboard systems. With higher levels of automation such complexity is expected to increase enormously. To address this problem, we propose a common taxonomy of vehicle display status and alerting terminology that is based on flight deck regulations in aviation and propose simple principles for their use in a man-aged display status and alerting system.

1. Introduction

In automotive vehicles of today, drivers do not currently find common ways of interacting with Automated Driving Assistance (ADAS) and Automated Driving (AD) functions. While international standards exist for controls and display symbols such as (*ISO 9241-210:2010 - Ergonomics of Human-System Interaction -- Part 210: Human-Centred Design for Interactive Systems*, n.d.) (*ISO 4040:2009(En), Road Vehicles — Location of Hand Controls, Indicators and Tell-Tales in Motor Vehicles*, n.d.)), the enabling, disabling, adjustment, and status display of such functions vary widely between vehicle brands and models. This can make it difficult for drivers to operate such modern vehicle for the first time or handle foreseen or unforeseen changes in the automation status where the driver has to quickly understand the demands of the situation (McCall et al., 2019) to appropriately respond. This is exacerbated by the fact that drivers retain less situation awareness during AD compared to manual driving (de Winter et al., 2014). Furthermore, the display of status and alerts of different functions may conflict with each other if they are not integrated and no common priorities of the alerts are defined and harmonized across brands and vehicles. Thereby the display of status information and alerts are critical for the driver to remain aware of the current mode of the driving automation function and respond to mode changes (e.g. (Endsley, 2016, 2019; Hancock, 2019)). To facilitate the safe use of automated functionality on the flight deck, management systems for status displays and alerts have been required on flight deck of airplanes for years, see e.g. (Abbott et al., 1996). We believe that similar developments will be necessary to facilitate safe and enjoyable AD in the automotive domain.

For this purpose, we propose in this paper a preliminary taxonomy of alerting levels and principles. In contrast to aviation, there seems no common definitions of display and alerting terms in the automotive domain. Agreed terminology seems a necessary precondition for converging technological developments, for example, SAE Standard J3016 (SAE International, 2021) defines critical terms for AD and thereby forms the starting point for many developments around the world. Therefore, we similarly propose a common terminology for the display of status and alerts for AD.

Specifically, we base this proposed terminology on an existing guidance document in aviation. There, CFR / CS § 25.1322 (Federal Aviation Administration, n.d.) provides guidance to avionics manufacturers to facilitate compliance of new flight-deck displays with aviation regulations. We apply this idea to the automotive domain. This work is performed by the EU H2020 project HADRIAN (Holistic Approach for Driver Role Integration and Automation Allocation for European Mobility Needs, see https://hadrianproject.eu/).

2. Taxonomy of Alerts and Indications

In automotive vehicles of today, drivers do not currently find common ways of interacting with Automated Driving Assistance (ADAS) and Automated Driving (AD) functions. While international standards exist for controls and display symbols such as (*ISO 9241-210:2010 - Ergonomics of Human-System Interaction -- Part 210: Human-Centred Design for Interactive Systems*, n.d.) (*ISO 4040:2009(En), Road Vehicles — Location of Hand Controls, Indicators and Tell-Tales in Motor Vehicles*, n.d.)), the enabling, disabling, adjustment, and status display of such functions vary widely between vehicle brands and models. This can make it difficult for drivers to operate such modern vehicle for the first time or handle foreseen or unforeseen changes in the automation status where the driver has to quickly understand the demands of the situation (McCall et al., 2019) to appropriately respond. This is exacerbated by the fact that drivers retain less situation awareness during AD compared to manual driving (de Winter et al., 2014). Furthermore, the display of status and alerts of different functions may conflict with each other if they are not integrated and no common priorities of the alerts are defined and harmonized across brands and vehicles. Thereby the display of status information and alerts are critical for the driver to remain aware of the current mode of the driving automation function and respond to mode changes (e.g. (Endsley, 2016, 2019; Hancock,

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2.1. Guiding Principles for the Display of Alerts and Indications Based on the defined terms, the guiding principles for the display of alerts and indications organize the display of them to help the driver interact and manage the AD system in consistent, expectable, and safe ways while minimizing discomfort. These principles are described next.

Warning alerts are displayed when drivers should become aware immediately of an event or change and act immediately. For example, to avoid an unforeseen obstacle the driver has to take back vehicle control immediately.

- Are intended for non-normal events or conditions where a time-critical response is required
- Are not part of the daily routine of operating a vehicle, therefore, drivers would experience warnings on an infrequent basis
- Include at least two modalities (e.g. visual and auditory) to increase likelihood of perception
- Are associated with a unique identifier (e.g. the color "red") that allows quick identification
- Include a highly salient cue to direct the drivers attention

Caution alerts are displayed when the driver should immediately be aware of an even or change and subsequent action is necessary (e.g. within 5 or 15 sec). For example: the driver has to take back control within a few seconds.

- Are intended for normal and non-normal events or conditions
- Are not usually part of the daily routine of operating the vehicle. Therefore, drivers may experience cautions on a more frequent basis than warnings. It remains to be seen how this can be quantified (e.g. less than once per trip ?)
- Are associated with at least two modalities (e.g. visual and auditory) to increase likelihood of perception
- Are associated with a unique identifier (e.g. the color "yellow") that allows identification
- Include a moderately salient cue to direct the drivers attention

Advisory alerts are displayed when the driver should be aware of this information but no immediate attention or action is required. For example: vehicle getting low on fuel

- Are intended for normal and non-normal events or conditions
- Are part of routine operations, the driver may experience these alerts on a frequent basis even multiple times during a trip.
- Are associated with at least two modalities
- Are associated with an alerting level identifier other than those for warnings and cautions

- Includes a low salience cue to facilitate the drivers attention

Indications are displayed to provide the driver with information about the ongoing status of the vehicle, driver, or environment. Examples: fuel-status, turn-signal sound, current ADL-mode. Indications may be preceded by advisories to get drivers awareness (e.g. low fuel-status advisory) and then stay on as reminders.

- Are intended for normal and non-normal events
- Are part of routine operations, the driver knows indications from daily operations.
- Are (usually) associated with only one modality
- Are associated with an identifier other than those for warnings, cautions, and advisories
- Not associated with a salience cue (though may be preceded by an advisory)

2.2 Guiding Principles of Alerting Prioritization. For a specific event, the selection of the appropriate level of alert should facilitate a safe outcome but also minimize the interruptions and driver discomfort. Especially high-level alerts should only be used when needed, i.e., when a time critical fast response from the side of the driver is required. Because warning level alerts may be presented at high levels of intensity (e.g. loud or shrill) to ensure awareness of the driver, they may be perceived as uncomfortable by the driver and be experienced as interruption. Furthermore, too many high-level alerts may desensitize the driver and reduce compliance for a quick response. Therefore, high level alerts should be used sparingly. Rather, it may be preferrable to precede higher-level alerts by lower-level alerts to provide more time for a staged response that induce less stress and therefore may help reduce error potential (Zirk et al., 2020).

2.3 Alerting Modalities The display of AD status and alerts may use various modalities that are discussed next.

Steering Wheel / Pedal Feedback: Traditionally, steering wheel and pedals are perceived as unidirectional actuators with a passive feedback, through which the driver commands the vehicle. Current technology allows to introduce active bidirectional communication through haptic feedback in these interfaces.

This haptic feedback can be conducted in two different ways. On the one hand, the vehicle can continuously apply certain torque at the steering wheel which is felt by the driver. The intensity of the torque informs the driver about the automation's preferred trajectories. This level of intensity is referred to as Level of Authority under the Haptic Shared Control (Marcano et al., 2020). For instance, it allows the vehicle to perform steering corrections, or to make a control transition during emergency situations. On the other hand, the vehicle can apply a vibration at the steering wheel to alert the driver of different situations (e.g., stepping into a line or to prevent the driver to execute a maneuverer).

Regarding the prioritization of the alerts, torque based haptic feedback displays all four alerting levels. For instance, in a lane centering system, *indication*s during regular driving conditions, could reflect as torque intensity the separation from the center of the lane through the driver's hands. *Advisory alerts*: As the vehicle approaches the safety threshold, the torque intensity increases noticeably, providing an advisory alert for the driver. *Caution alerts*: When the vehicle reaches the safety threshold, the torque intensity is complemented with a vibration to ensure getting driver's attention and guaranteeing situation awareness. *Warning alerts*: Eventually, if the safety threshold is crossed, a notch is applied by the vehicle indicating the need for an immediate action.

Kinaesthetic Feedback: Kinaesthetic cues are a form of haptic cues, that address the proprioception of a user. As of today, kinaesthetic cues are rarely used for driver-vehicle interaction, even though they may provide several benefits. First, such kind of cues are very easy to perceive and can be quickly processed. Second, the cues are solely perceived by the person who experiences them. Thereby, overly intrusive acoustic or visual signals can be avoided, yet achieving similar levels of driver awareness. However, haptic and kinaesthetic signals cannot convey a lot of information, and usually convey non-directional meaning. Thus, additional interpretational information needs to be conveyed using additional signals.

With regards to take-over requests though, it is possible to design a kinaesthetic cue so that the driver's attention is directed towards the intended interaction. Here, the driver can literally be pushed towards the driving task, either by a longitudinal or a rotational seat movement. As studies show a positive effect of haptic signals on TOR performance, a positive effect of such a kinaesthetic cue can be assumed as well (Zhang et al., 2019).

Head-Up Display Feedback: Head-up displays (HUDs) represent a state-of-art solution for displaying alerts and informational cues directly on the windshield, preferably in the driver's field of vision. Compared to the head-down display (HDDs) they reduce frequency and duration of glances required to perceive the information and therefore reduce driver distraction and potential error. The use of HUDs also proved to significantly reduce the response time to unanticipated road or traffic events. Using HUDs enables better and more consistent speed control and reduced cognitive workload, navigational errors, and better lateral vehicle control (Jakus et al., 2015).

2.4 Adaptivity of Alerting (Fluidity) Advisory and caution level alerts can adapt to the driver, vehicle and environment conditions to improve their efficiency and the user experience. This adaptivity can be thought of as the transportation of discrete signals into a continuum, where each alerting level is still clearly recognizable, but where the nuances of the specific signals allow for a more faceted, fluid and personalized experience, and ultimately increase safety.

At the driver level, the alerting can adapt to the specific driver to provide optimal experience and outcome. Specifically, the alerting can adapt to the amount of signaling a specific driver needs to initiate the appropriate action. A driver that has shown sufficiently compliant driving behavior may require less pronounced alerting signals than a driver who has previously not shown similar compliance. For example, if driver A is monitoring the environment as instructed whereas driver B is (too) often engaged in non-driving related activities and has received several advisories during the previous drive to monitor the environment better; Driver A may receive the same alert as driver B but at a lower-level of intensity to minimize the disruptiveness.

The adaptivity to the vehicle and environmental conditions can account for changes in, e.g., the noise level (music playing, construction works) and visibility conditions (dim lights, twilights) to ensure the alert is perceivable and unmistakable.

Conversely, indications that provide normal status information do not need to be adapted to increase the efficiency of driver's response, as their role is fulfilled when updated information are displayed. However, it would still be beneficial for the overall user experience to adapt, where possible, their graphical layout to the current layout of the (digital) instrumentation. For example, when the "sport" driving dynamics is selected, the instrumentation and corresponding indications can appear with the typical sharp, aggressive, intense design; while with "eco" driving mode active, the indications can turn green, soft, smooth, etc.

Finally, warning level alerts should not be adaptive, as their function is time and safety critical, requiring immediate awareness and response by the driver. Therefore, the unique audio/visual identifiers of those alerts should always provide the highest saliency and invariance.

2.5 Principles of AD Operations Whereas the proposed taxonomy certainly addresses AD as defined in (SAE International, 2018), the taxonomy also applies to the expanded Principles of AD Operation (Shi et al., 2020) which provides an even wider perspective for automation in the vehicle. According to the Principles of AD Operation Framework, AD systems that affect vehicle guidance (Donges, 2016) can be described by using three Principles of Operation. Principle of AD Operation A includes informing and warning functions. These functions are characterized by an indirect effect on vehicle guidance, i.e., they address a human driver who realizes an effect on vehicle motion control. Principle of AD Operation B includes functions that affect vehicle guidance directly and on a sustained basis, i.e., driv*ing* automation functions and is defined in SAE Standard J3016 (SAE International, 2018). Principle of AD Operation C includes functions that affect vehicle guidance directly and temporarily in accident-prone situations. (Shi et al., 2020) proposes further differentiation of these functions. From a human factors perspective, Principle of AD Operation A functions gain importance with increasing diversity of Principle of AD Operation B and C functions in modern vehicles.

3. Example of Alert Prioritization for Automated Driving at Level 3 with Driver Monitoring System

To motivate the applicability of the proposed taxonomy, we apply the taxonomy as an example to the transition from automated driving at SAE Level 3 (ADL3) to manual driving. In ADL3, the vehicle can operate lateral and longitudinal control in certain use cases as traffic jams. Since it further monitors the driving environment and responds appropriately, the driver remains a fallback-ready user who can perform non-driving related activities (NDRA). As soon as the vehicle sends a takeover request (TOR) or an evident system failure occurs, the fallback-ready user must take over control immediately [5].

For this example, it is further assumed that a driver monitoring system (DMS) is installed that observes the drivers status and condition to assert driver / user compliant behavior. For this, two categories of alerts are differentiated, either related to the *vehicle's automated driving state or events* (shown in blue diamonds in figure 1) or about the *driver status or behavior* (shown in green circles in figure 1). Since both categories of alerts are triggered by different events and require different responses by the driver they should be clearly and consistently distinguishable for the driver. The events are defined in Table 1.

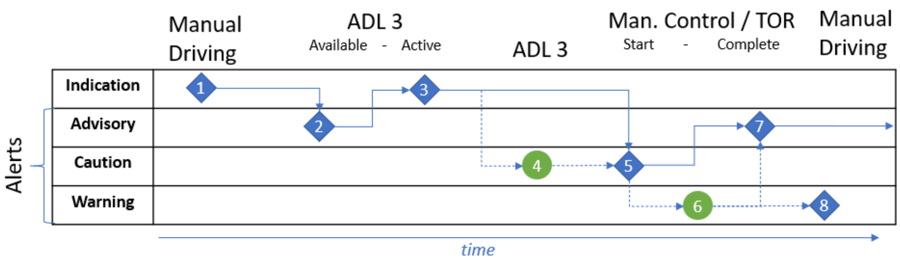

Figure 1 Application of Alert Taxonomy to ADL 3 - Manual Transition

Table 1 Explanation of Terms in the Example

	Event / Activity
1	Manual Driving
2	ADL 3 becomes available
3	ADL 3 is engaged (expected ADL duration is also displayed)
4	Driver performs non-compatible NDRA (conditional)
5	ADL 3 will need to terminate

6	Driver performs insufficient transition / take-over (conditional)
7	Driver has started to drive manually again

4. Conclusions

In this paper we proposed a taxonomy of terms for AD status display and alerting that is centered around the expected human driver responses. We expect this proposal to be fruitful for discussions and refinement and help to eventually lead toward a world-wide harmonization of interactions between drivers and AD and thereby facilitate safe, acceptable, and sustainable market penetration. Validation activities will be needed to ascertain these promises for specific implementations. Such validation activities are foreseen to happen along several steps. First, the taxonomy is applied to a specific alerting function in the vehicle and consistent alerting modalities are derived. Thereby, also variants should be explored and, if possible, a baseline configuration against which performance can be compared. Secondly, in empirical studies including driving simulators or real vehicles (e.g. including wizard-of-oz arrangements) drivers are exposed to different situations within which the alerting system is experienced. Early study iterations may consist of subjective walk-throughs with drivers to identify optimization options and possible confusing arrangements. Later study iterations attempt to quantify the performance impact. Evaluation conditions should include both normal (non-alerting scenarios), true-alerting scenarios, as well as nuisance-alerting and missed-alerting scenarios. Primary metrics for such evaluations consist of response time, response characteristics, quality of the response, as well as qualitative assessments of the alerts and the response performance among various display variants.

In addition to such validation studies, the alerting taxonomy is expected to be useful as guideline and principle of display design to harmonize vehicle cabin environments that allow drivers to better expect and use alerting and display systems across vehicle models and brands.

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Biography

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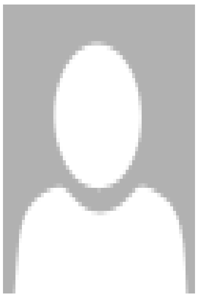

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