Design Principles for Advanced Driver Assistance Systems: Keeping Drivers In-the-Loop

International Harmonized Research Activities (IHRA) Working Group on ITS

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Preface

Technological development and innovation have provided rapid progress in sensors and vehicle control. Fully automated vehicles have already been demonstrated on real roads. In time, safe and efficient automated vehicles will have a significant impact on the road trauma. Prior to full automation, we will have the stage of partial automation, where drivers stay involved in some way or another in vehicle control. This means the driver and vehicle will still have to cooperate on their roles and share responsibilities. Some tasks may be better managed by the system while others have to remain with the driver. This optimal level of autonomy in vehicles needs to be determined (Sheridan, 1992).

Automation should provide users with safe, comfortable, convenient and efficient mobility. However, drivers need to be aware of the road traffic situation around their vehicle at any given moment. They should also be able to anticipate relevant changes in the road traffic situation. This document describes some of the human factors issues associated with driving task automation. It sets out some basic principles that will help to optimize system performance and avoid drivers being out-of-the-loop and unprepared to manage safety-critical situations when they are needed. When the advanced driver assistance systems control or support elements of the driving task, drivers should be fully aware of the performance and limitations of those functions.

This document was prepared by the IHRA working group on Intelligent Transport Systems (ITS) to support the activities of the UNECE WP.29 ITS informal group. It was written to be widely applicable to the design and manufacture of advanced driver assistance systems.

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1. Introduction

Automated control systems are becoming more common in new road vehicles. In general, automation is designed to assist with mechanical or electrical accomplishment of tasks (Wickens & Hollands, 2000). It involves actively selecting and transforming information, making decisions, and/or controlling processes (Lee & See, 2004). Automated vehicle control systems are intended to improve safety (crash avoidance and mitigation), comfort (decrease of driver's workload; improved driving comfort), traffic efficiency (road capacity usage; reduced congestion), and the environment (decreased traffic noise; reduced fuel consumption).

The automation of basic control functions (e.g., automatic transmission, anti-lock brakes and electronic stability control) has proven very effective, but the safety implications of more advanced systems are uncertain (e.g., adaptive cruise control and lane keeping assistance). Given that problems occurred with automation in the skies (e.g., Weiner & Curry, 1980), problems on the road should also be expected, possibly to a greater extent. The driving environment is less predictable than the flying environment because the margins of error are smaller, and the typical driver has almost no expertise or training on the systems. It is not clear that system safety will always be enhanced by allocating functions to automatic devices rather than to the drivers. Automation, by taking away the easy parts of a task, can make tasks more difficult (Bainbridge, 1987). Of particular concern is the out-of-loop performance problems that have been widely documented as a potential negative consequence of automation (e.g., Weiner & Curry, 1980).

Advanced Driver Assistance Systems (ADAS) use sensors and complex signal processing to detect and evaluate the vehicle environment; this includes the collection and evaluation of infrastructure-based data, if available. They provide active support for lateral or longitudinal control, information and warnings (RESPONSE, 2001). Tasks carried out by ADAS range from information to collision avoidance and vehicle control. In ADAS, warning and control each have an important role to play for safety enhancement, and these systems can be categorized based on the levels of assistance that they provide to drivers (See Figure 1, adapted from Flemisch et al., 2008).

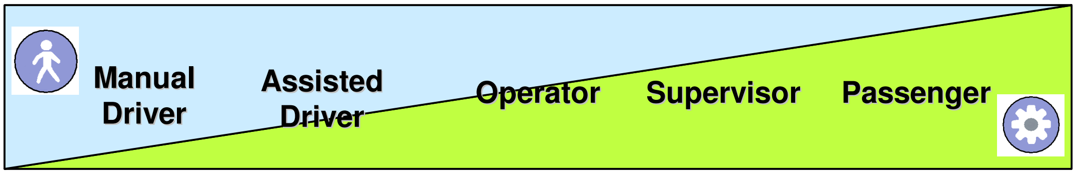

Figure 1. Role Spectrum in Vehicle Automation (Flemisch et al., 2008).

Figure 1 illustrates the progression of assistance and the associated roles of the driver (Flemisch et al., 2008). The spectrum ranges from the vehicle being fully controlled by a human driver (manual/ conventional driving) on the left to being a fully automated system where the driver's role becomes that of a passenger.

Figure 2 illustrates how ADAS assist drivers in the tasks of detection, judgment, and operation (Hiramatsu, 2005). When no ADAS are present during conventional driving, drivers monitor the feedback of the vehicle behaviour. They detect and recognize elements in the driving environment, make judgments about imminent risks, if these occur, and about the future effects of any actions they take; and take control of the vehicle and carry out the consequent maneuver to mitigate the risk (Ho, 2006).

At Level 1, ADAS provides the least assistance (see Figure 2). These ADAS present information acquired from sensors to the driver, and assist them only with the *detection* of relevant information. They enhance the perception of drivers by aiding their awareness of the driving environment, but do not provide warning alerts. An example of such ADAS is a Night Vision System, which creates a visual image of the roadway ahead based on infrared sensors and thermal imaging technology, and provides that image via a Heads-Up Display (HUD), thereby aiding the driver while driving in the dark (Ho, 2006).

Level 2 ADAS offers aid to drivers by assisting their assessment of the criticality of hazards through warnings to help drivers avoid critical situations. This works with detection of the driving environment that's also provided by Level 1 ADAS. Examples of Level 2 ADAS are the Forward Collision Warning (FCW) system and the Lane Departure Warning (LDW) system.

At Level 3, ADAS provides more assistance to the driver through vehicle *control*, and avoids or mitigates hazards actively, without direct input from the driver. These intervening assistance systems have a higher level of automation and a lower level of driver control. The level of automation can range from overriding and taking partial control, to full control, which would represent autonomous driving. These

ADAS relegate drivers from being manual controllers to supervisory controllers. An example of Level 3 ADAS is the Adaptive Cruise Control (ACC), which detects obstacles in front of the driver and intervenes on its own by using evasive measures, such as applying the brake to adjust the speed in order for the headway not to exceed a certain threshold. Another example is emergency mitigation braking, which is issued to mitigate crash severity in the situation where the crash is determined to be unavoidable. As a consequence, Level 3 ADAS has two features; one is for systems used in the normal driving situation such as ACC, and the other in the abnormal driving situation such as emergency mitigation braking.

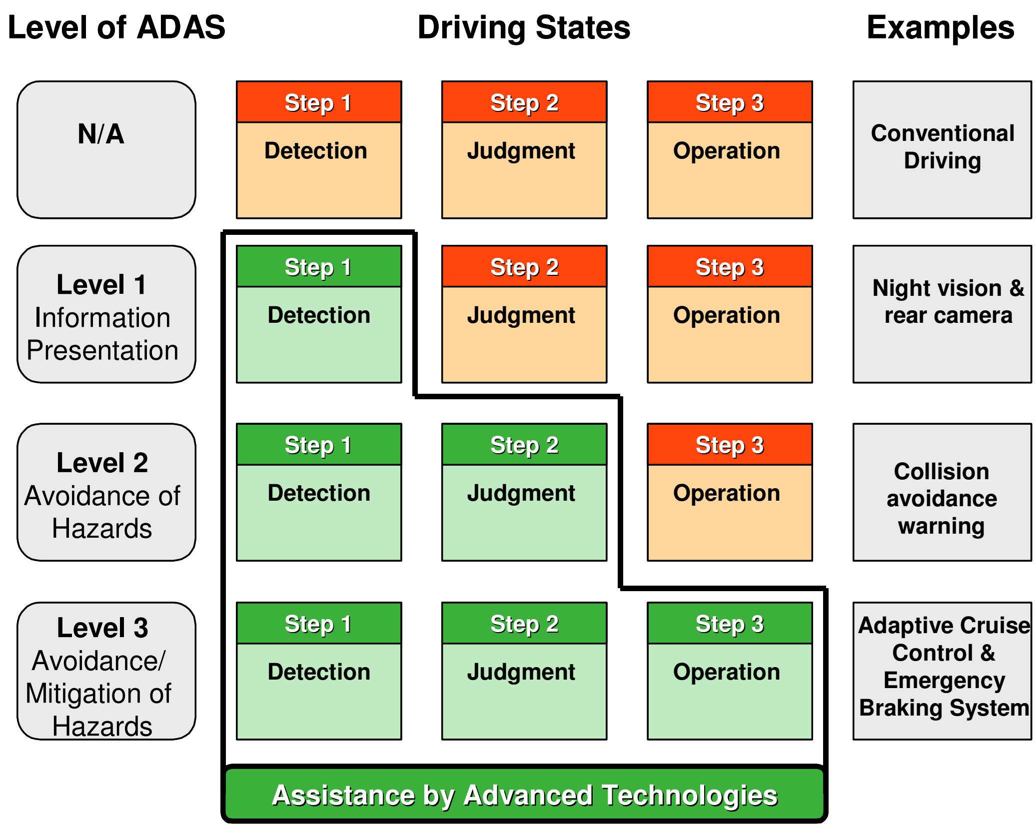

Figure 2. Behavioural Model of a Driver and Level of Driver Assistance

2. Human Factors in Driving Automation

The introduction of automation in vehicles poses a host of human factors concerns (e.g., Sheridan, 1992). Advanced automation can fundamentally change the driving task and the role of the driver in the road-traffic environment. In addition to facilitating driver performance, the introduction of automation in cars also has the potential for deteriorating performance (Young & Stanton, 1997). The following sections summarize the main issues relating to the automation of the driving task.

Driver Mental Workload is a central concern for automation. It has been suggested that automation has dual effects on mental workload (Stanton, Young & Walker, 2007). Automation could decrease driver workload in some situations, if it takes over driving activities; or it can increase attentional demand and mental workload in other areas, such as trying to keep track of what the automation is doing. In the former situation, fewer driving tasks may result in driver *underload* through reduced attentional demand. The latter case could lead to driver *overload*, which can occur under conditions of system failure or when a driver is unfamiliar with the system (Brook-Carter & Parkes, 2000). Both overload and underload can be detrimental to performance (Stanton et al., 2007).

Although automation is usually intended to lighten workload, this is not necessarily beneficial for driving and does not always lead to increased road safety. When a given level of automation lowers drivers' mental workload to the point of underload, there is the possibility that should a device fail, the driver is faced with an explosion of demand to circumvent an accident. In certain cases drivers cannot cope with this occurrence, which could cause a crash (Young & Stanton, 1997).

ADAS may take over a large proportion of the workload, which would lead drivers to overestimate system performance and, as a result, to drive more passively. A more complacent or passive attitude can lead to further problems such as monotony and fatigue (Thiffault & Bergeron, 2003). Situation awareness and response time may be affected by automation because it takes operators "out-of-the-loop". Drivers tend to use less effort with automation, or their task changes from active control to supervisor or even passenger. A psycho-physiological consequence of less activity is reduced alertness. Alternatively, alert drivers may take advantage of this reduction in task demand to do something else (e.g., multitask). It has been suggested that the basic goal should be to optimize – not reduce – workload, which would entail a balancing of demands and resources of both task and operator (Young & Stanton, 1997; Reichart, 1993; Rumar, 1993).

Trust in automation, to a large degree, guides reliance on automation. Lee and See (2004) have argued, "People tend to rely on automation they trust and tend to reject automation they do not" (p. 51). Too little trust may result in technology being ignored, negating its benefits; and too much trust may result in the operator becoming too dependent on the automated system (Parasuraman & Riley, 1997). In other words, drivers may undertrust and therefore underutilize automated assistance systems; or they may overtrust and consequently overly rely on the systems. Generally, trust appears to be largely regulated by the driver's perception of the system's capability. Specifically, if the system is being perceived as being more capable to carry out the task than the driver, then it will be trusted and relied on, and vice versa (Young, 2008). Also, trust is generally considered to be a history-dependent attitude that evolves over time (Lee & See, 2004). In addition, this evolution of trust will differ between systems that operate in normal and abnormal driving situations. In the normal driving condition, trust may lead to heavy reliance if the driver perceives the system as being reliable over time. In abnormal driving situations, drivers may not have the opportunity to experience the system and develop the high level of confidence needed to trust systems that automatically perform safety-critical actions.

Rudin-Brown and Parker (2004) tested drivers' levels of trust with the ACC before and after use and found that the degree of trust in ACC increased significantly following exposure to the system. Creating trustworthy automated systems is therefore important. Appropriate trust and reliance are based on how well the capacities of vehicle automation are conveyed to the driver, and thus driver awareness and training are essential (Lee & See, 2004).

Behavioural Adaptation As with any changes in the driving environment, the introduction of ADAS may lead to changes in driver behaviour. Behaviour changes caused by the introduction of ADAS are a major challenge for the efficiency and safety of these systems. Behavioural adaptation is "an unintended behaviour that occurs following the introduction of changes to the road transport system" (Brook-Carter & Parkes, 2000; OECD, 1990). These negative adaptations may reduce some of the planned safety results of ADAS. For example, ADAS may take over a large proportion of the workload, which would lead drivers to overestimate system performance and, as a result, to drive more passively.

3. Driver-In-The-Loop

The notion of *driver-in-the-loop* means that a driver is involved in the driving task and is aware of the vehicle status and road traffic situation. Being in-the-loop means that the driver plays an active role in the driver-vehicle system (see Figures 1 and 2). They actively monitor information, detect emerging situations, make decisions and respond as needed. By contrast, *out-of-loop* performance means that the driver is not immediately aware of the vehicle and the road traffic situation because they are not actively monitoring, making decisions or providing input to the driving task (Kienle et al., 2009). Being out-of-loop leads to a diminished ability to detect system errors and manually respond to them (Endsley & Kiris, 1995).

The Vienna Convention for Road Traffic, a treaty founded in 1968, was designed to increase road safety by standardizing the uniform traffic rules at an international level. Several articles in the Vienna Convention are relevant to the discussion of automation and control in vehicles. Specifically Articles 8 & 13 require that drivers be in control of their vehicle at all times. This may not always be the case with some autonomous driving functions. The issue of consistency between the Vienna Convention and the vehicle technical regulations developed by WP.29 and WP.1 (Working Party on Road Traffic Safety) is currently being discussed. Some countries, such as the United States and Canada, did not sign the treaty.

An example of an ADAS that could potentially remove the driver from the loop is Adaptive Cruise Control (ACC), which automatically adjusts the vehicle's speed to maintain a set distance to the vehicle in front. A tendency to over-rely on the ACC function may lead to drivers becoming passive observers and losing a portion of their normal awareness of the driving situation. Another circumstance where ADAS may remove the driver from the loop would be a lane keeping assistance system coupled with ACC. If drivers only periodically monitor the vehicle instead of being in control, they could become out of the loop. Failure to notice a hazard may result in confusion due to a lack of understanding of the warning system's response to the hazard. Generally, when out of the control loop, humans are poor at monitoring tasks (Bainbridge, 1987).

Research findings on the effect of in-vehicle automation on situation awareness are mixed. For example, Stanton and Young (2005) found that situation awareness was reduced by the use of ACC. Similarly, Rudin-Brown et al. (2004) found that drivers tend to direct their attention away from the driving task and toward a secondary task (e.g., using an in-vehicle telematics device) while using ACC. However, Ma and Kaber (2005) found that in-vehicle automated systems generally facilitate driver situation awareness. They reported that the use of an ACC system improved driving task situation awareness under typical driving conditions and lowered driver mental workload.

Keeping the driver-in-the-loop is also particularly relevant to the occurrence of traffic incidents, where good situation awareness is crucial for drivers to be able to effectively cope with the situation. As such, a major research objective in ADAS research is to determine what techniques are optimal for keeping the driver-in-the-loop during automated control. A premise based on the above-mentioned human factors in vehicle automation is that driver involvement in car driving, under typical driving conditions, would be maintained at an optimal level if

- mental workload would be at a moderate level
- there would be good situation awareness throughout the drive
- drivers would have appropriate trust in the automated system(s), and
- negative behavioural adaptation (compensating behaviours) would not occur.

Automated in-vehicle systems developed and designed with these principles in mind would support and enhance the task of driving a car. Furthermore, ensuring that, during ADAS development, drivers stay informed and in control can avoid (or reduce) errors due to out-of-the-loop control problems. A challenge for ADAS research is to determine how to measure situation awareness in the context of driving, understand how it varies, estimate its preferred level and how that can be maintained. There is an increasing call for understanding the implications of vehicle automation on driver situation awareness (Ma & Kaber, 2005). Operational definitions and characteristics of underlying task and environment factors associated with driver situation awareness are needed.

4. Driver-in-the-Loop Principles

Scope These principles apply to systems that partially or fully support elements of the driving task. These principles also apply to systems that can actively change vehicle speed, direction, lighting or signaling.

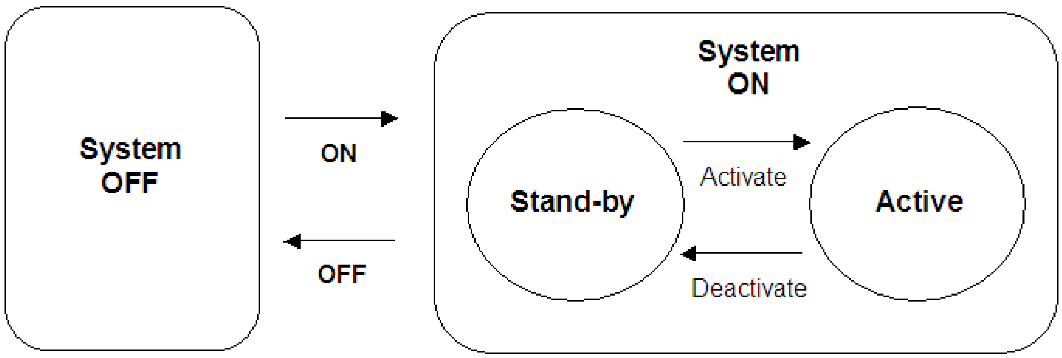

Figure 3. Generic State Transition Diagram for Active Vehicle Control Systems

The system should provide the following basic driver interface and intervention capabilities for active vehicle warning and control systems.

4.1 Control Elements – Normal Driving Situations

- System actions should be easy to override quickly at any time under normal driving situations and when crashes are avoidable.

4.2 Control Elements – Abnormal Driving Situations

- When the crash is determined to be unavoidable, the system can take actions to try to mitigate the crash severity.
- When a loss of control is determined to be unavoidable, the system can take actions to try to regain stability and control.
- When it determines that driver performance is impaired, the system can take actions to avoid or mitigate collisions.

4.3 Operation Elements

- For systems that control the vehicle under normal driving situations, the driver should have a means to transition from ON to OFF manually and to keep the system in the OFF state.
- Drivers should be informed of the conditions that result in system activation and deactivation.

- Drivers should be informed of the conditions when system operation is different or is not guaranteed.

4.4 Display Elements

- It should be made clear to the driver what assistance systems are installed on the vehicle.
- For systems that have a means to manually transition from ON to OFF, the driver should be able to easily determine the system state.
- System active status shall be displayed to the driver. The driver should be provided with clear feedback informing them when the system is actively controlling the vehicle.
- Drivers should be notified of any transfer of control between the driver and vehicle.
- If action or information is not available due to a failure, the driver should be informed.
- If symbols are used to notify the driver, a standard symbol should be used.

5. Development Process for Automated Vehicle Systems

The impact automation has on driver performance and safety is complex and multidimensional. A systematic process is needed to ensure that these design principles are addressed during ADAS design and development. For example, the RESPONSE 3 project (2009) developed a Code of Practice for the design and evaluation of advanced driver support and active safety systems. It is assumed that such a process will be beneficial to establish safety objectives and acceptance criteria. Risk analyses, driver-in-the-loop testing and related evaluations would also be carried out as part of this process. Human factors design principles should be followed. Displays should be noticeable and designed appropriately so they do not distract, overload or confuse drivers. Human factors task analysis and user needs studies should be conducted to determine the need for automation and appropriate level of automation. Automation should not be used unless some benefits can be demonstrated in terms of improved safety (crash avoidance and mitigation), comfort (decrease of driver’s workload; improved driving comfort), traffic efficiency (e.g., road capacity usage; reduced congestion), or the environment (e.g., decreased traffic noise; reduced fuel consumption). Extensive system and user testing should be done in the field to fully understand the impact the technology has on safety. This testing is needed to demonstrate that the systems enhance or have a neutral impact on safety. Any evidence of a negative impact on safety should be examined carefully. Testing should be done on representative samples of drivers under both common and challenging situations.

6. Summary

There is a need to better understand the risks of automation in passenger vehicles, to identify where problems may occur and to determine how they can be prevented or diminish their consequences. Ongoing research and development of ADAS is essential, as is the continual introduction of ADAS into the market so that the public can benefit from these technologies. This document describes some of the human factors issues associated with driving task automation. It also provides a set of basic design principles that will help to limit some of the problems associated with out-of-loop driving. The application of these principles will help to keep drivers involved in the driving task and aware of the vehicle status and road traffic situation. The automated systems will then be more transparent and easier to understand. Their application will help to avoid situations where the driver is out-of-the-loop and unable to detect system errors and less prepared to respond in critical situations.

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