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# Design Principles for Control Systems of ADAS

This text was reproduced with reference to the discussion results of the last meeting of ITS Informal Working Group, held on 16th Friday, March, 2012. As a next step, in accordance with the programme of work, it will be submitted to WP29.

**Contents**

## 1. Preface

ADAS (Advanced Driver Assistance Systems) have been developed to support drivers and enhance road safety. Among the products on the market are warning systems to advise of a safety hazard; control systems to improve the ease of control during normal driving and help avoid accidents and/or mitigate the crash severity in critical situations. In June 2011, the WP.29/ITS Informal Group developed and proposed basic guidelines for imminent warning systems, part of which was already referred to in the regulatory discussion of AEBS (Advanced Emergency Braking Systems) and LDWS (Lane Departure Warning Systems).

Studies on control systems are under way in various countries and regions, but they have not yet resulted in internationally uniform guidelines. However, control systems require a certain basic understanding for development, because it is imperative that the average driver is able to safely and comfortably operate these systems according to his/ her intentions and take full control as needed. To address this concern, Europe has conducted studies under the RESPONSE 3 project and Japan similar studies under the ASV project.

This document focuses on control systems among ADAS and summarizes the minimum necessary principles that are of vital importance for HMI (human-machine interaction) in the use of control systems. Considering that newly developed control systems are still on the way and that a variety of systems will be marketed in the future, this document focuses on general principles that are applicable across the board and not those applicable only to specific systems.

In the main text of this document, we first describe the principles that are important for HMI in the use of ADAS. For control systems, there are twelve principles in total. Next, in the form of an annex, we summarize some issues in automation, important viewpoints and future tasks for HMI based on findings and experience. Reference is made to the influence of further automation of these systems that is expected as control systems evolve.

This document was drafted by the IHRA (International Harmonized Research Activities)-ITS working group, revised several times, and then submitted to the ITS Informal Group. The next step is left to the discretion of the ITS Informal Group. It should be noted that this document is not aimed at regulation but was written as a reference for the stakeholders who are engaged in the design and development of human-centered ADAS.

## 2. Scope

ADAS can be classified into three categories: information provision, warning, and control. Guidelines for limiting driver distraction from in-vehicle information systems have already been established and are used on a self-commitment basis. Regarding warnings, the ITS Informal Group submitted the "Guidelines on establishing requirements for high-priority warning signals", which was adopted at the 154th session of WP.29 in June 2011.

This document discusses control systems that support and assist the driver's driving operations. Systems covered include those that involve a certain interaction (transfer of control) between the driver and the system, but exclude those that control the driving operations independently. Therefore, this document does not discuss existing ABS (Anti-lock Braking Systems) and ESC (Electronic Stability Control), nor does it cover information provision systems such as navigation devices.

In this document, we discuss systems that are used during normal driving, such as ACC (Advanced Cruise Control system) and LKS (Lane Keeping-assistance System), as well as systems used in critical situations, such as AEBS (Advanced Emergency Braking Systems), to avoid accidents and mitigate crash severity. AEBS are currently being regulated, but we include them in our discussion because they involve the transfer of control between the driver and the system.

The present principles are applicable mainly to passenger cars (M1), but the basic philosophy is applicable to other categories of vehicles. Therefore, it is desirable that they are also applied to vehicle categories such as M2, M3, N1, N2, and N3. The principles are expected to apply to both original equipment and aftermarket devices. It should be noted, however, that there may be some difficulties coordinating aftermarket devices with the control systems fitted by vehicle manufacturers.

## 3. Existing Regulations

There are two existing regulations which are most relevant to the principles in this document.

/ Regulation No. 121 VEHICLES WITH REGARD TO THE LOCATION AND IDENTIFICATION OF HAND CONTROLS, TELL-TALES AND INDICATORS
/ FMVSS No. 101 Controls and displays.

The Working Party on Brakes and Running Gear (GRRF) is developing the following new regulations.

- Regulation on Advanced Emergency Braking Systems (AEBS)
- Regulation on Lane Departure Warning System (LDWS)

## 4. Control Principles

The principles are divided into four sections:

- Control elements;
- Operational elements;
- Display elements and
- Supplementary elements.

We established a total of twelve principles. Each principle defines the minimum requirements to be fulfilled for the HMI to allow the driver to easily and accurately understand and judge driving situations and effectively use the control system according to their intentions.

The section on control elements and operational elements is divided into those for normal situations and those for critical situations, and an explanation is given on how the control system should be operated. In the section on display elements, the discussion covers the notification of normal functionality, failure, reduction in the scope of functionality, and the transfer of control. The section on supplementary elements includes a warning against over-reliance on sensors and systems, which is potentially dangerous, and discusses the use of standard symbols and information for road users.

In this document, normal driving refers to situations that do not require immediate responses from the driver and/or vehicle to avoid a collision. Critical driving refers to situations that do require immediate responses from the driver and/or vehicle to avoid or mitigate a collision.

### 4.1 Control Elements

(i) System actions should be easy to override at any time under normal driving situations and when collisions are avoidable.

Explanation: One of the main objectives of ADAS such as ACC, etc., used in normal driving situations, is to reduce the driving workload. During normal driving, the system should be capable of being overridden by the driver using simple, deliberate action(s) at any point in time.

(ii) When a collision is determined to be imminent, the system can take actions intended to avoid and/or mitigate the crash severity.

Explanation: In critical driving situations where the driver has not taken proper avoidance actions because of impairment, distraction, inattention, or other unforeseen incidents, it should be possible to apply system intervention to try to avoid the collision or mitigate the crash severity.

### 4.2 Operational Elements

(iii) 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.

Explanation: For ease of use and/or convenience in driving, the driver's intentions should be ensured as a priority, so that the driver can switch the state of control from system to driver, that is from ON to OFF, and the OFF state should be kept under the driver's operation.

(iv) For systems that control the vehicle under critical driving situations, the initial set state of the system should be ON.

Explanation: For collision avoidance and/or mitigation, the first priority is to reduce trauma, therefore the system status ON should be maintained during driving and should be clearly visible to the driver. However, accounting for driver preferences, the system can be equipped with a manual OFF switch.

**4.3 Display Elements**

(v) Drivers should be provided with clear feedback informing them when the system is actively controlling the vehicle's speed and/ or path.

Explanation: When the system is actively controlling the vehicle, the driver should be provided with clear feedback on its activation. The driver has to be made aware of system activation so as to properly manage driving a car with assistance systems.

(vi) Drivers should be informed of the conditions when system operation is malfunctioning or if when there is a failure.

Explanation: When the system is malfunctioning or has failed, the driver should be informed of the system status. This is needed to avoid any misunderstanding by the driver that the system is still working.

(vii) Drivers should be informed of the conditions when system operation is not guaranteed.

Explanation: When the system is not fully functioning, for example, the sensor performance is impaired under certain driving conditions such as rain or when road markings are not visible, the driver should be informed of the status to allow a smooth transfer of control to the driver.

(viii) Drivers should be notified of any system-initiated transfer of control between the driver and vehicle.

Explanation: Transfer of control between the driver and the vehicle would be the point when automation is realized. Any transfer of control should be transparent to the driver, but at the very least, the driver should be notified of any transfer initiated by the system so the driver is always aware if they have control of the vehicle.

### 4.4 Supplementary Elements

(ix) In cases where systems automatically control the longitudinal and lateral behaviour of the vehicle, and the driver's task is to monitor system operations, appropriate arrangements should be considered to ensure drivers continued monitoring of the vehicle, road and traffic situation.

Explanation: When the driver is using highly automated systems such as ACC with LKS, which is the automation of longitudinal and lateral control, the driving tasks are reduced and the driver simply monitors the systems and surroundings. In these situations, it is important to ensure the driver's attention to the driving task is maintained. To ensure that the driver stays aware of the driving situation, appropriate measures should be considered to keep the driver in-the-loop.

(x) Drivers should be notified of the proper use of the system prior to general use.

Explanation: The manufacturer should provide information on correct system use to avoid any misunderstanding and/or over-dependence on the system. For example, it is required that the driver understand what assistance systems are installed in the vehicle, and that instructions be provided on the physical limitations of the system functions prior to its use.

(xi) If symbols are used to notify the driver, a standard symbol should be used if available.

Explanation: Taking into account the use of different and/or unfamiliar vehicles, commonality of information should be secured, therefore standard symbols should be used, if available. Regulation No.121 could be the one that might be referred.

(xii) System actions should be displayed to other road users.

Explanation: To help surrounding road users, such as other drivers, pedestrians, and cyclists, be aware of vehicle actions, the system's actions should be displayed when braking, changing lanes or for hazards. In consideration of the system functions and driving situation, the need for display might be determined on a case-by-case basis.

## 5. Summary

ADAS control systems are still being developed and various new systems will emerge in the future. For the development of technologies, it is important to continuously improve the safety and user-friendliness of these systems for the average driver. If a negative effect is felt, these systems may lose credibility among the general public and subsequent development may be hindered. To prevent such an event and to encourage proper development of the systems, it is important to define the principles to be followed as a basic guideline.

These principles are limited to the minimum requirements of critical importance. However, systems that arrive on the market in the future may require guidance for aspects that are not covered. Changes over time may also make some of the principles obsolete or unnecessary. The present principles must therefore be revised as appropriate, and this task should be assigned to the ITS Informal Group, since the present principles deal with ADAS in general and not with specific systems.

As a future process, the UNECE WP.29 ITS Informal Group and other relevant working groups in the UNECE WP.29 will engage in comprehensive discussions on a mechanism that will ensure effective implementation of the control system principles. As the timeline, we plan to prepare a draft in 2011 to 2012, examine it at each GR in 2012, and prepare a revision for discussion at the WP.29 in 2013.

# Annex: HMI Considerations for Control Systems of ADAS

This document describes some of the human factors issues associated with driving task automation.

## A1 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). It is controversial that system safety will always be enhanced by allocating functions to automatic devices rather than to the drivers. 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).

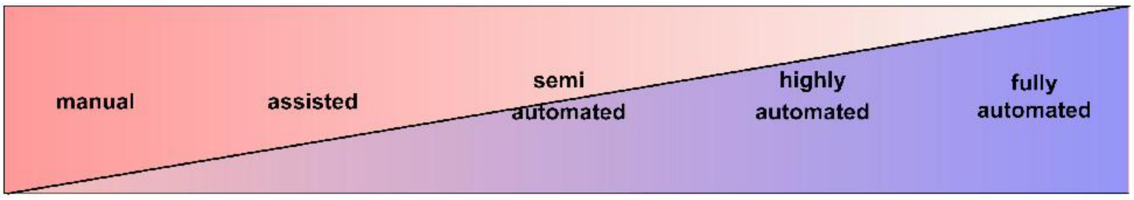


Figure 1. Role Spectrum in Vehicle Automation (Flemisch et al., 2008).

Figure 1 illustrates the progression of assistance and the associated roles of the driver (Flemisch et al., 2008). The manual driver means that the driver manually controls the vehicle without any assistance systems. The assisted driver implies that the driver is supported mainly by warning systems such as forward collision warning and lane departure warning. In semi-automated, about half of the driving tasks are automated illustrating ACC in which the driver executes main control over the lateral vehicle guidance whereas the automation executes control over the longitudinal guidance. In highly-automated, the automation executes control of essential parts of the driving task, such as integrated lateral and longitudinal control and the driver mainly monitors the automation, takes over when necessary, hand-on or hand-off driving can be both classified as highly automated.

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 Route Guidance System that helps the driver look for the route to destination. Different example of Level 1 is rear vision camera that shows the area behind the vehicle and provides information. – if it provides an alert then it is a Level 2 system.

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. An example of Level 3 ADAS is the Adaptive Cruise Control (ACC) + the Advanced Emergency Braking System (AEBS), which detects obstacles in front of the driver and intervenes on its own by using avoidance and/or mitigation measures, such as applying the moderate and/or rapid brakes to adjust the speed in order for the headway not to exceed a certain threshold. 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 critical driving situations such as AEBS.

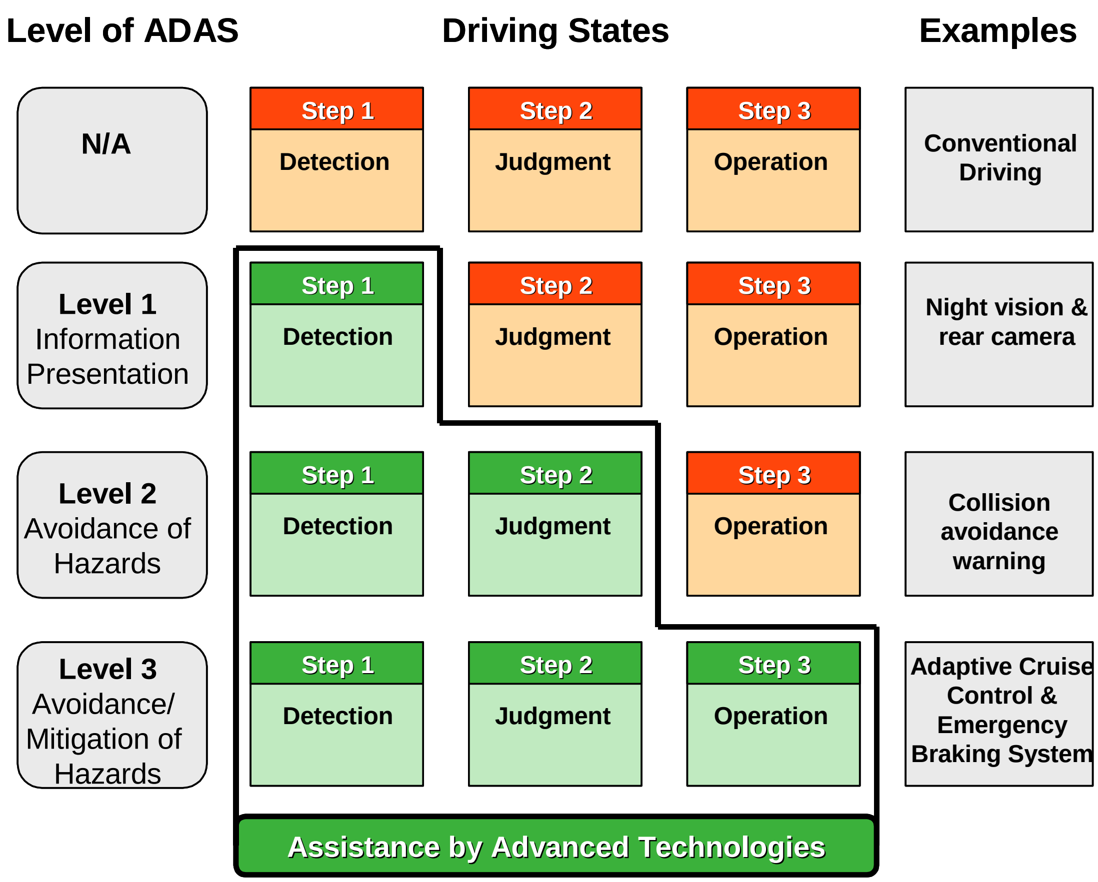


Figure 2. Behavioural Model of a Driver and Level of Driver Assistance

**A2 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.

- Workload:

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).

Automation is usually intended to lighten workload, but 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, and 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:

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 critical 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 critical 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).

- Adaptation:

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.

## A3 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.

It will be difficult to make a line between in the loop and out of the loop. For example, the task monitoring the systems and surroundings could be out of the loop if the driver's attention shift away from the situation, but it could be in the loop if he/she carefully monitors them. This mentions that the line between them could ramify according to how much the driver be aware of the driving situation.

Automation may be relevant to likelihood for causation of out of the loop. 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. On the contrary, there is another view that ACC requires steering operation and that keeps driver in the loop.

A 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 control 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.

### A4 Future Work

Automation will bring the car driving more convenient and safe, however it will also cite some concern that automation could lead the driver to be less aware of the driving situation and increase risk. For the proper development of automation in vehicles, it will be needed to promote further research works on the points as follows:

- To develop how to measure situation awareness in the context of driving, understand how it varies, estimate its preferred level and how that can be maintained.
- To clarify what is underload or overload and how to measure it, and how to avoid over-dependency in accordance with the change of driver behavior as a result of adaptation.
- To explore how to retain the responsibility in car driving when the automation level highly increases.

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