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Guidelines on establishing requirements for high-priority warning signals with GRE comments to WP.29-150-22

UNECE/WP29/ITS Informal Group

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Preface

Advanced Driver Assistance Systems (ADAS) technologies represent important advances in vehicle safety and it is crucial to optimize their potential. WP29 established ITS Informal Group in 2002

The Inland Transport Committee organized a Round Table Conference on ITS in 2004, and reached an agreement of continuation of the activity of the WP.29 Informal Group on ITS. The TOR (Terms of Reference) submitted in 2004 described that ITS Informal Group should develop a common understanding of driver assistance systems, to exchange information and views on technology trends, and to review activity in the second year to WP29.

One of the important outcomes through two years of activity in 2005 and 2006 was consensus on common understanding for ADAS. That is, ADAS can be classified into three categories as information provision, warning and control. Guidelines for information have been already established and used ~~as~~ on a self-commitment basis. The ITS Informal Group will keep monitoring the situation for developments and will provide updates.

On the other hand, for warning and control, no rules or guidelines were seen at the moment. Control systems were still premature at that time, so the ITS Informal Group decided to focus on warnings which play~~s~~ an important role for safety enhancement. Effective warnings have a potential of compensating for the known limitations of drivers and thus preventing road trauma.

In 2007, the ITS Informal Group asked the International Harmonized Research Activities (IHRA-ITS WG) to work together to prepare the draft statement of warning principles. In November 2008, IHRA submitted the final draft statement to ITS Informal Group at its 16th session, where the Group agreed to hold its adhoc meeting to discuss the contents of the document. The adhoc meeting was held in September 2009.

Herein, the ITS Informal Group provides the proposal of Statement of Principles on the Design of High-Priority Warning Signals for Advanced Driver Assistance Systems. The ITS Informal Group expects that this document will be finalized by WP29 as a guideline so that relevant GRs could refer to it, when necessary.

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1. Introduction

Advanced Driver Assistance Systems (ADAS; e.g., forward collision warning or lane departure warning systems) are designed to help drivers avoid, or mitigate, the effect of crashes. High-priority warning signals are presented by these systems to promote awareness and timely and appropriate driver action in situations that present potential for, or immediate danger, of serious injuries or fatalities.

With regard to Human-Machine Interface (HMI) guidelines on the display of information to drivers, Europe already has its Statement of Principles (ESoP), North America the Alliance principles, and Japan the Automobile Manufacturers Association guidelines, all of which are effective on a voluntary basis. However, these principles apply to the design of in-vehicle information and communications systems and not warning systems. Warning systems are different in many ways from in-vehicle information and communications systems, and as a consequence, should benefit from separate guidelines.

Some guidelines do exist for warning systems. For example, there are some ISO standards that provide specifications for certain types of systems, or certain aspects of warnings. Japan has also established its own HMI considerations for infrastructure-based driving assistance systems that display information, cautions and warnings to drivers (Japan ITS Promotion Council, 2007), yet there are no generic warning-related guidelines that have been globally agreed upon.

The purpose of this document is to highlight human factors principles and practices for the design of high-priority warning signals on ADAS. Each of the principles should be considered during the design of the high-priority warnings. The application of these principles should help to make warnings interfaces that are more noticeable, easier for drivers to understand, less confusing, and more predictable.

This document also provides stakeholders with an overview of relevant guidelines and standards and information on how to access them. However, the principles are not a substitute for any current regulations and standards, which should always be taken into consideration. Accordingly, this document may be referred to when designing the high-priority warning systems, but compliance with the principles is not mandatory.

Finally, it should be noted that the objective values in this document are raised as illustrations based on state of the art research results, they can be improved and adjusted according to the further findings. Any future innovations designed to enhance vehicle safety should not be precluded from the scope of these guidelines.

1.1 Characteristics of Warnings

Tingvall (2008) describes the sequence of events leading up to a crash. These are normal driving, deviation from normal driving, emerging situation, critical situation and crash unavoidable. Each of these stages can be seen as defining a set of countermeasures. These principles focus on the critical situation; the last few seconds that provide an opportunity to avoid a crash. High-priority warnings can be defined as in-vehicle safety communications that inform drivers of the need to take immediate action or decision to avoid a potential crash that could result in serious injuries or fatalities. Available studies indicate that there are typically three levels of warning priority:

1. Low-level - driver prepares action or decision within 10 seconds to 2 minutes; may escalate to a higher level if not acted upon

2. Mid-level - requires action or decision within around 2 to 10 seconds; may escalate to high-level warning if not acted upon

3. High-level - warning requires the driver to take immediate action or decision (0 to around 2 seconds) to avoid a potential crash that could result in serious injuries or fatalities.

High-priority, or high-level, warnings may occur without notice, or follow a lower level warning that has escalated. Warnings that are urgent, but have minimal consequences are not always highest priority. For example, a turn instruction from a navigation system may require a prompt response; however, the consequences of missing that signal are not necessarily dangerous. Warnings that could have severe safety implications, yet do not require an immediate response from the driver, are not the highest priority. For example, a sensor failure would not usually require an immediate action from the driver.

High-priority warnings are not necessarily the best way to protect people and property. There may be more effective or more reliable strategies. One approach is to eliminate the hazard if possible through improved design. For example, it may be preferable to design vehicles with clear rearward visibility rather than to rely on a sensor-based back-up warning system to inform drivers of obstacles. Or, if the hazard cannot be eliminated, then some form of protection could be used to limit damage. For example, if rear visibility cannot be improved through vehicle design, an ADAS could potentially be used to prevent a vehicle from reversing into an obstacle. High-priority warnings are justified where hazards cannot be prevented or protected. In practice, a combination of warning and intervention will often be the most successful strategy.

1.2 Scope

These principles mainly apply to in-vehicle collision warning systems on road passenger vehicles (passenger cars and UN-ECE M1 type passenger vehicles), however the principal idea will be common among other vehicle classes such as M2, M3, N2 and N3. Table 1 lists some ADAS systems that may be within the scope of these principles. These principles are not restricted specifically to collision warnings, and they may also be relevant to other vehicle warning systems. The principles can be applied to original equipment and aftermarket devices. On the other hand, it should be noted that there could be some difficulties at the moment for the aftermarket devices to cooperate with the warning systems developed by car manufacturers.

ADAS that do not warn, such as lane keeping assistance, parking aids, and night vision systems, are not within the scope of these principles. As well, these principles do not apply to less urgent or less critical warning systems, such as advanced warnings for speed, curves, crash black spots and road works. However, they may nevertheless be appropriate, helpful, and relevant to these types of systems.

Table 1. ADAS Systems with High-Priority Warnings.

Forward collision warning systems (FCW)
Lane departure warning systems (LDW)

Road departure warning systems (RDWS)

Back-up warning systems

Blind-spot warning systems

These principles apply to driver-in-the-loop systems that warn or provide drivers with support in avoiding crashes. This means that these principles do not apply to fully automated systems (e.g., ABS: Antilock Brake System, ESC: Electric Stability Control) or in-vehicle information and communication systems (e.g., navigation systems). They apply to systems that require drivers to make one, or more, of the following responses:

- Immediate braking for evasion of crash,
- Immediate steering manoeuvre for evasion of crash,
- Immediate termination of initiated action,
- Seek awareness of situation and perform one of the above responses, and
- Immediate decision to retake control by the driver.

This document concerns only the design of high-priority warning displays. It does not cover driver responses and system controllability, although there is a need for guidance on these issues as well.

These principles should only apply to systems which are not yet in the scope of existing regulations. Systems meeting existing regulations and/or standards are deemed to be in line with the generic principles defined in this document.

1.3 Driver Perception-Response

As the sequence of events leading up to a hazardous situation escalate, the opportunity to respond diminishes. Warning systems function to elicit an appropriate avoidance response from the driver (see Figure 1). To achieve this, the warning signal needs to attract the driver's attention (detection) and inform them of the situation. The driver then needs to understand the signal (identification), choose an appropriate response (decision) and take action (response). The entire perception-response sequence needs to be completed before a conflict becomes unavoidable. For high-priority warnings, the time between warning signal onset and crash event may be around 2 seconds. This leaves very little margin for delay or error. This perception response sequence becomes fast and reflexive for very well practiced driving behaviours and the sequence may be slower for situations and responses that are unexpected or less familiar to the driver.

In case that the driver may notice the situation as it evolves, the high-priority warning may either help confirm the existence of an emerging conflict or be considered a nuisance for the driver who is already aware of the situation and/or in the process of responding.

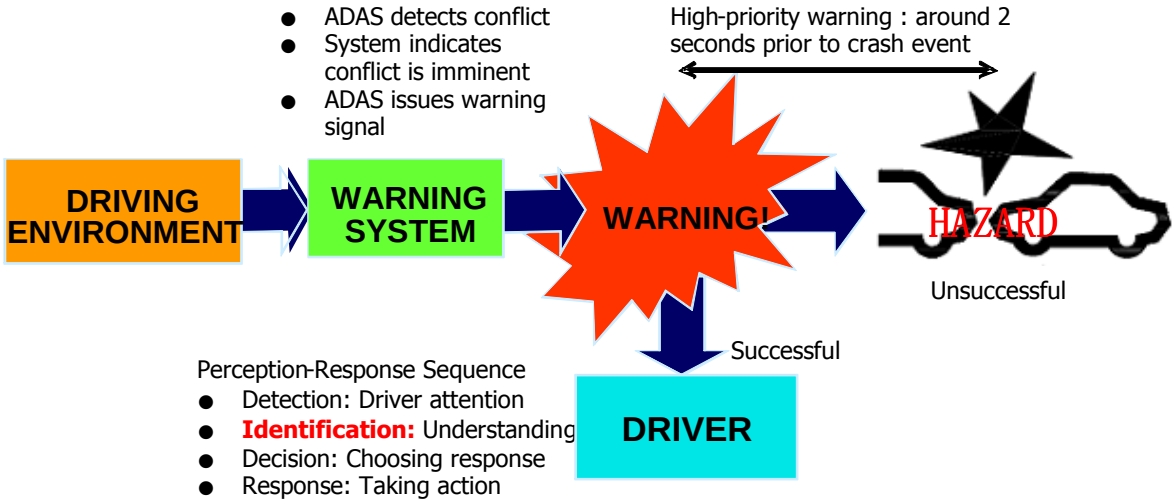

Figure 1. Perception-Response Sequence for High-Priority Warnings

A total of eight principles for high-priority warnings were derived from the literature on warnings research and guidelines. These principles are as follows:

1 High-priority warning should be noticeable in the driving environment.

2 High-priority warning should be distinguishable from other messages.

3 High-priority warning should provide spatial cues to the hazard location.

4 High-priority warning should inform the driver of proximity of the hazard.

5 High-priority warning should elicit timely responses or decisions.

6 Multiple warnings should be prioritized.

7 False / nuisance warnings rate should be low.

8 System status and degraded performance of high-priority warnings should be displayed.

There is some redundancy among these eight principles. The first four principles relate to Detection and Identification, numbers 5 and 6 correspond to Decision and Response, while numbers 7 and 8 concern the driver's awareness of system state, trust and reliability.

2. Existing Standards

The International Standards Organization (ISO) has two working groups that develop standards specifically related to high-priority warnings for in-vehicle ITS. The first is Vehicle/Roadway Warning and Control Systems (TC 204 WG 14). This group has developed the following standards:

- ISO 15622 Adaptive Cruise Control (ACC)

- ISO 15623 Forward Vehicle Collision Warning
- TS 15624 Roadside Traffic Impediment Warning
- ISO 17386 Maneuvering Aid for Low Speed Operations
- ISO 17361 Lane Departure Warning

This group is currently working on standards for: lane change decision aids, full speed range ACC, low-speed following, forward vehicle collision mitigation and intersection signal information and violation warning.

The second ISO group is: Road vehicles – Ergonomic aspects of transport information and control systems (ISO TC22/ SC13/ WG8). WG 8 is currently working on principles for the integration of time-sensitive and safety-critical warning signals in road vehicles. This group has produced a technical report on warnings (Konig & Mutschler, 2003) and several relevant procedures and specifications such as:

- ISO/TS 16951- Procedures for determining priority of on-board messages presented to drivers
- ISO 15006 – Road vehicles - Ergonomic aspects of transport information and control systems - Specifications and compliance procedures for in-vehicle auditory presentation

The Safety & Human Factors Committee of the Society of Automotive Engineers (SAE) also develops standards for in-vehicle ITS. Some of the existing standards and current work items are as follows:

J2395 - Its In-Vehicle Message Priority (2002);

J2399 - Adaptive Cruise Control (ACC) Operating Characteristics and User Interface (2003);

J2400 - Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements (2003);

J2808 - Road/Lane Departure Warning Systems: Information for the Human Interface (2007);

J2397 - Integration of ITS In-Vehicle User Interfaces Standard;

J2398 - In-Vehicle ITS Display Legibility Standard;

J2478 - Proximity Type Lane Change Collision Avoidance;

J2802 - Blind Spot Monitoring System (BSMS): Operating Characteristics and User Interface.

The standards that emerge from these ISO and SAE working groups tend to represent the points of consensus within the automotive industry.

3. Statement of Principles

The following principles should be considered during the design of high-priority warnings for ADAS.

3.1 High-priority warning should be noticeable in the driving environment

The high-priority warning should be detectable during typical driving conditions. Potential sources of irrelevant signals and ambient noise in the vehicle, which may mask high-priority warnings, should be identified.

A high-priority warning display that does not have an effective means to capture the driver's attention is likely to be missed. A visual display, for example, may not be seen if the driver is looking in a different direction.

To make the warnings noticeable, one should not exaggerate warning levels. Such improper designs of overly bright signals, sound levels that are too loud and too much haptic excitation might result in driver distraction, annoyance, or startle the driver, causing the driver to take inappropriate action.

There are three different sensory modalities that can be used to warn drivers: visual, auditory and haptic (i.e., tactile-kinesthetic or proprioceptic). Table 2 lists some of the relevant dimensions of these three sensory modalities.

Table 2. Modes and Dimensions of Warnings

Modality	Dimensions
1. Visual	Colour Symbol Text Size Brightness/Intensity Contrast Location Flashing Duration
2. Auditory	Sound type (speech, tone, auditory icon) Loudness (absolute and relative to masking threshold) Muting or partial muting of other sounds Onset and offset Duration (pulse, pulse interval) Musicality Frequency Spatial location
3. Haptic	Vibration/Frequency Location Intensity Direction Duration (pulse, pulse interval, pattern or rhythm)

According to multiple resource theory (Wickens, 1992), multiple stimuli presented in the same modality (e.g. more than one visual input) will have a greater tendency to interfere with one another. Warnings presented in only a single modality may be missed if that modality is already occupied. Presentation in more than one modality, may generally serve to increase the probability of perception. This redundancy of presentation may also, depending on the system, reinforce the salience of the message and the perception of urgency, which may increase the likelihood that a driver will make a timely response. In several cases, research shows that human response is more rapid when warnings are presented in more than one modality (Belz et al., 1999), and that drivers have a preference for multimodal presentation (Lui, 2001). The use of distributed presentation also increases the opportunity to display information on the nature of the hazard, thereby increasing the likelihood of an appropriate response.

According to ISO 15006 - "A auditory signal concerning the safety of the driver or other people, and requiring immediate action of the driver, shall not be presented exclusively by auditory means, but shall also be presented using another sensory channel. Other modes for presenting the information may be visual, haptic and/or kinaesthetic. Redundancy is necessary because, owing to hearing impairment or masking ambient auditory noise, some drivers will not be able to perceive the auditory signals".

As a consequence, two modalities or more are generally recommended to make high-priority warnings more noticeable, however the warnings can be displayed using one modality if it can be ensured that the driver will notice the warning. One modality presentation should be avoided in those cases where the drivers line of sight may deviate from the direction of the visual warnings or, for auditory warnings, where the driver's ability to hear the auditory warnings could be impaired.

High priority warnings are more noticeable when they are:

Displayed in two modalities:

Visual Warnings (COMSIS, 1996 and Campbell et al., 2007)

- Redundant - Visual warnings could be used to supplement, or be redundant with, auditory or haptic warnings.

- Location/ size – Visual warnings should be visible from the driver's normal relevant viewpoint. The warnings should not obstruct the driver's field-of-view. Visual warnings should not be designed to cause conflict with other visual warnings.

  According to some research results, warnings located within 15 degrees of the passenger car driver's expected line of sight can make the warnings more noticeable to the driver. Location of visual warnings will be different between passenger cars and trucks, because of the difference in their vehicle characteristics and dimensions of the vehicle interior.

- Brightness - Visual warnings should have a luminance that can be detected by the driver.

  According to some research results, a luminance of approximately twice that of the immediate background is more noticeable under most driving conditions.

- Activation - Flashing can be effective in attracting the driver's attention to the signal.

According to some research results, flashing at a rate around 4hz can be effective in attracting the driver's attention to the signal.

- Colour – high priority warnings should have red as their main colour, taking into account that text in red colour may be difficult to read.

- Auditory Warnings (COMSIS, 1996 and Campbell et al., 2007)

- Display Type - Use tones with intermittent pulses or warbling sounds.

- Intensity - warning signals should be noticeable enough for the driver to the signals, but should not cause a startle effect. In particular, care should be taken for coach passengers not to provoke fearful conduct. Care should also be taken for the presentation of auditory warnings to the elderly drivers who may suffer from impaired hearing ability in higher frequency

Haptic Warnings (COMSIS, 1996 and Campbell et al., 2007)

- It may be desirable in many cases for haptic warnings to have continuous physical contact with the driver.

- Haptic warnings should be sufficiently intense so that drivers can feel them during foreseeable driving situations, but should not interfere with their ability to respond.

Examples:

Good: A forward warning system that displays a visual warning of an obstacle and also provides a brief brake pulse to alert the driver of a potential crash with a vehicle ahead.

Bad: A collision warning system that provides only an auditory alert. This may not be useful to some hearing impaired drivers and will likely not display salient information such as the location of the hazard.

3.2 High-priority warnings should be distinguishable from other messages in the vehicle

High-priority warnings need to be clear to drivers and understood without confusion. They should be easily and quickly recognizable to allow a timely and appropriate driver response. Warnings can be distinguished along the dimensions listed in Table 2. Situations in which potential conflicts between high-priority warnings and low priority messages should be identified and signals should be designed to avoid potential conflict. For example, warnings sharing an interface, and requiring different responses, should not be in conflict with each other.

Examples:

Good: The driver is able to discriminate high-priority warnings and other messages, so that they can take appropriate response to avoid the critical situation. For example, the FCW warning signal can be instantly distinguished from ITS service messages such as parking information etc.

Bad: High-priority warning signal ‘A’ is masked by other warnings, so that the driver is not likely to perform the appropriate avoidance response. For example, visual and auditory displays are almost similar between a FCW warning signal and ITS service message such as parking information etc.

3.3 High-priority warnings should provide spatial cues to the hazard location

In general, high-priority warnings need to inform drivers of the general direction of hazards, which can be located to the front, sides, rear and corners of the vehicle. Orienting a driver to the source of a hazard can hasten responses and lead to more appropriate responses.

Orientation cues can be conveyed by visual, auditory and tactile displays. Tan and Lerner (1996) found that perceived location of auditory alerts, if properly designed, could assist drivers in focusing their attention in the right direction to respond to a possible collision threat.

If it is not possible to provide a spatial cue, care needs to be taken not to orient the driver inappropriately – away from the hazard or appropriate response options. In some demanding situations, drivers may not perceive the subtle location of information.

Examples:

Good: Detecting the following vehicle with excessive high speed, blind spot warning system warns the driver, who has just issued lane change signals without noticing the following vehicle. It does this with an urgent visual display in the center console illustrating the direction of the following vehicle.

Bad: A FCW detects an obstacle immediately in front of the vehicle and warns the driver by flashing a telltale up on the rear-view mirror.

3.4 High-priority warnings should inform the driver of proximity of the hazard

High-priority warnings need to be designed to inform the driver of the proximity of the hazard.

The driver needs to know proximity of the hazard in order to be able to make a timely and appropriate response. Therefore, the high-priority warning signal needs to be quickly and easily understood. Systems may also suggest the required avoidance response. Current technical limitations, and concerns over legal responsibilities, leave the decision of how to respond with the driver.

High-priority warnings occur in critical situations and will be infrequent under normal driving conditions. Consequently, such warnings need to be effective without in-depth training.

Examples

Good: A high-priority warning that displays easily recognizable information for proximity of the hazard.

Bad: A high-priority warning that provides no indication for the time demand of avoidance manoeuvre.

3.5 High-priority warnings should elicit timely responses or decisions

High-priority warnings should allow drivers sufficient opportunity to perform an appropriate avoidance response.

In-vehicle high-priority warning systems increase a driver's opportunity to avoid threats. Timely responses are critical for collision avoidance. Earlier warnings, in some situations, may provide drivers with more time to respond appropriately to successfully avoid a situation; however, they may become a nuisance if they are frequent and unnecessary (Lee et al., 2002). This might cause drivers to deactivate the system. The timing of warnings needs to account for driver perception-response times, as well as the need to limit the occurrence of false alarms. The criteria for triggering a warning requires a balance between the goal of providing greater protection and the occurrence of false or nuisance alarms (Lerner et al., 1996).

In the case of emergency braking responses, drivers that are fully expecting a hazard have an estimated median reaction time of 0.6 to 0.65 seconds. Drivers responding to unexpected but common hazards, such as brake lights, have an estimated median brake reaction of 1.15 seconds, while drivers responding to complete surprise events have an estimated median brake reaction time of 1.4 seconds. (Campbell et al., 2007). ~~).~~ Less information is available on the time to execute steering avoidance manoeuvres. Research suggests that greater time margins are needed to warn drivers for steering avoidance manoeuvres (e.g., > 1.2 seconds; Uno and Hiramatsu, 1997).

Examples:

Good: A FCW signal comes on with sufficient time for most drivers to detect the warning, choose an avoidance response and take action.

Bad: A FCW warns the driver too late, when it is no longer possible to avoid or mitigate the collision. Or, it warns the driver too early, and the signal becomes a nuisance.

3.6 Multiple warnings should be prioritized

To be effective, multiple warnings need to be prioritized so that the most urgent and critical messages are effectively communicated to the driver.

When multiple in-vehicle systems are present, different warnings and messages will be presented to drivers at various times. Performance and safety can potentially be affected if these messages are not managed properly and they occur simultaneously (ISO/TS 16951, 2003). Drivers may fail to obtain critical safety information, and lower priority messages might interfere with, and delay, driver responses to high-priority situations. This principle does not apply to "low priority warnings", where the requirements for the warning are set out in legislation, for example safety belt reminders.

Warnings can be managed by prioritization procedures that establish the relative timing and urgency of messages. There is an ISO technical specification that establishes some prioritization methods for in-vehicle messages (ISO/TS 16951, 2003). Prioritized warnings will help to avoid confusing the driver with overlapping signals. Prioritization helps to determine when, where and how system messages are delivered. It sets the relative importance of two or more messages, determining their ranking in a time sequence or emphasis of presentation. The primary ISO method calculates a priority index when the system is designed or updated, based on the criticality and urgency ratings of the messages. High-priority warnings are both critical (severe consequences if ignored) and urgent.

On the other hand, prioritization should take into account other legal constraints in terms of lower-level warnings which may be mandated by other regulations.

- High-priority warnings need to be displayed while the high-priority situation exists. In the case of simultaneous high-priority warnings, an appropriate warning strategy needs to be considered.

Examples:

Good: ITS service messages such as parking information etc. (low priority) is delayed while forward collision warning is displayed (high priority).

Bad: ITS service messages such as parking information etc. (low priority) and forward collision warning (high priority) are simultaneously displayed, and consequently the driver cannot understand the latter.

3.7 False / nuisance warning rate should be low

False warnings and miss rates need to be low. False alarms, or false positives, are warnings that are issued when the situation is normal. Misses, or false negatives, occur when no warnings are given although the decision threshold has been attained.

Safety must not be compromised by the introduction of ADAS. Systems need to be as reliable as possible because reliability is one of the most crucial determinants of driving response (e.g., Ho, 2006). High false alarm rates reduce driver trust in the system, which in turn can reduce response time, or lead to the driver wanting to turn the system off. Perfect system performance is not a realistic objective for many systems and false alarms can be expected. However, these need to be kept at a minimum so as to maintain drivers' trust and confidence in the system.

Nuisance warnings are warnings that occur when the driver is already aware and in control of the situation. Too many nuisance alarms can be irritating and may reduce the utility of the system. Providing some control over sensitivity settings may help to improve acceptance and performance. Adjustable warning thresholds can be possible to help reduce nuisance alarms, as long as the minimum threshold is designed with the intention of providing the driver with sufficient time to respond.

3.8 System status and degraded performance of high-priority warnings should be displayed

Ideally, the driver needs to be informed whenever the system is malfunctioning.

- Visual, auditory and haptic signals can be used to indicate the onset of a system malfunction.

- If the system is default-on and an on/off switch is provided, the driver needs to be informed whenever the high-priority warning system is off.

4. Warning System Development Process

A systematic, explicit, comprehensive and proactive process is needed to ensure that these warning principles, and other safety and human factors considerations, are addressed during ADAS design and development. For example, the RESPONSE 3 project (2006) developed a Code of Practice for designing, developing and validating 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.

5. Future Work

This document is intended to lay down recommendations for designers and manufacturers concerning high-priority warnings for driver assistance purposes. For the effective use of this document, the following matters should be deliberated:

- The UNECE WP.29 ITS informal group, and perhaps other relevant working groups in the UNECE WP.29, engage in comprehensive discussions on a mechanism that will ensure an effective implementation of the warning principles.

- If necessary, further research and development be undertaken on warning system assessment methods, including testing procedures and performance measures, in order to put the high-priority warning principles into practice.

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