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Statement of Principles on the Design of High-Priority Warning Signals for In-Vehicle Intelligent Transport Systems - Draft

International Harmonized Research Activities (IHRA) working group on Intelligent Transport Systems (ITS)

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Preface

Advanced Driver Assistance Systems (ADAS) are becoming more common in vehicles. These technologies represent important advances in vehicle safety and it is crucial to optimize their potential. At the same time, ADAS design and technology is evolving rapidly, so standard specifications do not exist yet for their design and performance.

In ADAS, warning and control each have an important role to play for safety enhancement. Effective warning has a potential of compensating for the known limitations of drivers and thus preventing road trauma. This document is therefore intended to provide a set of recommendations to be observed by the designers and manufacturers of ADAS with regard to imminent warnings for driver assistance purposes.

Regarding the characteristics of warnings, no common policies exist at the moment for their design. Meanwhile, there is concern that drivers might be confused by the presence of various types and permutations of warning systems on the market. Consequently, we recognise the importance and the need for a global approach rather than multiple different local solutions.

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. While hoping that the document will be used widely for the design and manufacture of warning systems, IHRA also recognizes that it is the UNECE WP.29 who will decide on utilization methods of this document on the basis of recommendations from its ITS informal group.

Finally, some advanced safety technologies have already been commercialized, but many are still under development. Consequently, we have a good opportunity to lay down principles and guidelines in a manner that should not hinder advances in technologies; rather it should encourage the research and development of warning system assessment methods, including testing procedures and performance measures.

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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 or immediate danger.

With regard to Human-Machine Interface (HMI) guidelines on the display of information to drivers, Europe already has its Statement of Principles (EsoP, 2005), North America the Alliance principles (2002), and Japan the Automobile Manufacturers Association guidelines (JAMA, 2004) 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 have separate requirements.

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 rules that have been globally agreed upon.

The International Harmonized Research Activities (IHRA) working group on Intelligent Transport Systems (ITS) has identified the importance of international guidelines for the design of effective, high-priority warnings and offers this document as a proposal for the UN-ECE WP.29 ITS informal group's consideration.

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 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. The principles are, however, not a substitute for any current regulations and standards, which should always be taken into consideration.

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. 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 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 2 seconds) to avoid a potential crash.

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. The term warning in this document refers to high-priority warnings.

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. 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). Other vehicle classes are not within the current scope of these principles. Table 1 lists some ADAS systems that are 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.

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 system.

Table 1. ADAS Systems with High-Priority Warnings.

Forward collision warning system (FCW)
Lane departure warning systems (LDW)
Road departure warning system (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, ESC) 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.
- 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.

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 response may be less than 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.

The curved arrows in Figure 1 illustrate that the driver may also notice the situation as it evolves. In this respect, the 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.

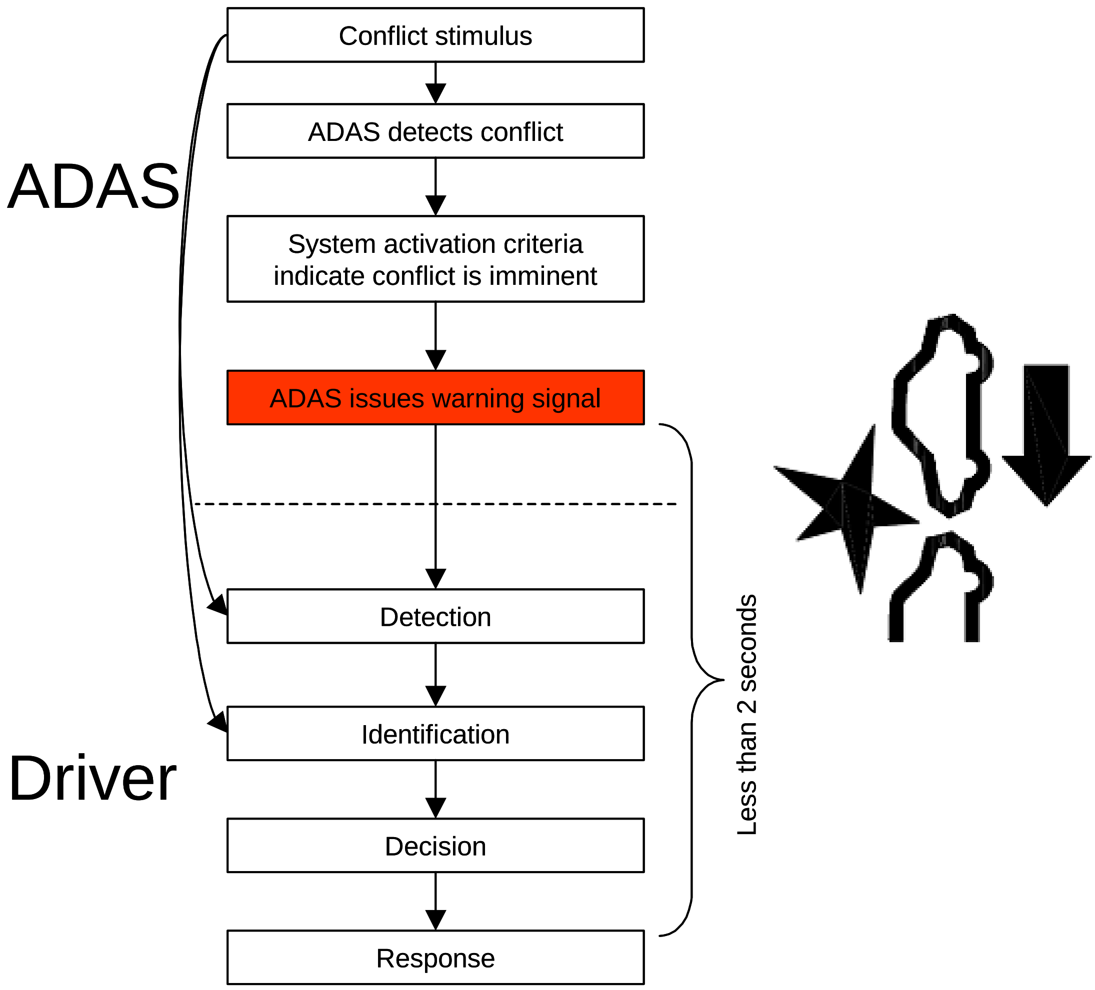

Figure 1. Perception-Response Sequence for High-Priority Warnings

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 Warnings should be noticeable in the driving environment.

2 Warnings should be distinguishable from other warnings.

3 Warnings should provide spatial cues to the hazard location.

4 Warnings should inform the driver of the hazard.

5 Warnings should elicit timely responses or decisions.

6 Multiple warnings should be prioritized.

7 False / nuisance warnings rate should be low.

8 Non-operational system status and degraded performance of 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 and 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 - Specifications and compliance procedures for in-vehicle auditory information 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 Warnings should be noticeable in the driving environment

The warning should be detectable during typical driving conditions. Potential sources of irrelevant signals and ambient noise in the vehicle, which may mask warnings, should be identified. Controllable signals in the vehicles that could interfere with the perception of the warning should be suppressed when the warning is presented.

A 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, too loud sound levels and too much haptic excitation might result in driver distraction, annoyance, or startle the driver, and cause 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, therefore, will generally serve to increase the probability of perception. This redundancy of presentation also reinforces the salience of the message and the perception of urgency, which may increase the likelihood that a driver will make a timely response. 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.

To make warnings more noticeable, high-priority warnings should be:

- Displayed in a least two modalities.

<u>Visual Warnings (COMSIS, 1996 and Campbell et al., 2007)</u>

- Redundant - Visual warnings should 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 be designed to cause the driver to look in the direction of the crash threat, yet the warnings should not obstruct the driver’s field-of-view. Avoid locating visual warnings adjacent to other visual information that could potentially clutter the signal.

It has been found that warnings located within 15 degrees of the drivers expected line of sight are more noticeable.

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

  It has been found that a luminance of approximately twice that of the immediate background is more noticeable under most driving conditions.

- Activation - visual warnings should start with an abrupt onset. Flashing can be effective in attracting the driver's attention to the signal. Other flashing displays should be avoided unless they are for already standard applications such as turn signals and hazard indicators.

  It has been found that 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 primary colour.

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

- Display Type - Use tones with intermittent pulses or warbling sounds.
- Intensity - warning signals should be in a certain range above the masked threshold, but should not exceed 90 dBA.
- Other auditory signals in the vehicle should be muted, or reduced in intensity, during the presentation of an auditory warning.

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

- The haptic warning display should 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 Warnings should be distinguishable from other messages in the vehicle

Warning messages should be clear to drivers and understood without confusion. They should be immediately 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 exist 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 between warnings, so that s/he can take appropriate response to avoid the critical situation. For example, the FCW warning signal can be instantly distinguished from the LDW signal or service messages.

Bad: Warning signal ‘A’ is masked by other warnings, so that the driver is not likely to perform the appropriate avoidance response. For example, the only difference between a FCW warning signal and a LDW signal, or service message, is a small text label.

3.3 Warnings should provide spatial cues to the hazard location

In general, warnings should inform drivers of the general direction and proximity of hazards. Hazards can be located to the front, sides, rear and corners of the vehicle. They can be near, far, stationary and approaching. 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 should 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: A FCW, detecting an obstacle immediately in front of the vehicle, warns the driver with an urgent visual signal that conveys the proximity and appears to come from the same general location as the threat.

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

3.4 Warnings should inform the driver of the hazard

High-priority warnings should be designed to inform the driver of the nature of the hazard.

The driver needs to know what the hazard is in order to be able to make a timely and appropriate response. Therefore, the warning signal should be quickly and easily understood.

Systems may also suggest the required avoidance response. Current technical limitations, and concerns over legal responsibilities, leave the decision how to respond with the driver.

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

Examples

Good: A warning that displays easily recognizable information (e.g., road departure, front obstacle).

Bad: A general warning that provides no indication of the nature of the warning.

3.5 Warnings should elicit timely responses or decisions

Warnings should allow drivers sufficient opportunity to perform an appropriate avoidance response.

In-vehicle warning systems increase a driver's opportunity to avoid threats. Timely responses are critical for collision avoidance. Earlier warnings, may in some situations, 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 should 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, chose 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

Multiple warnings should 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.

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.

- High-priority warnings should always be displayed because they are the highest priority. In the case of simultaneous high-priority warnings, an appropriate warning strategy should be considered.

Examples:

Good: A low fuel warning (low priority) is delayed while a lane departure warning is displayed (high priority).

Bad: The driver is given a turn instruction from the navigation system at the same time as a collision warning.

3.7 False / nuisance warnings rate should be low

False warnings and miss rates should 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 should 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 should 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 help to 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 Non-operational system status and degraded performance of warnings should be displayed

To the greatest possible extent, the driver should be informed whenever the system is malfunctioning or is performing outside of its operating conditions (non-functioning).

- Use a brief tone, followed by a continuous visual message to indicate the onset of a system malfunction or limitation condition (COMSIS, 1996)

- If an on/off switch is provided, the driver should 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:

- That 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.

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

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