TECHNICAL REPORT

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# Road vehicles — Ergonomic aspects of transport information and control systems — Introduction to integrating safety critical and time critical warning signals

*Véhicules routiers — Aspects ergonomiques des systèmes d'information et de contrôle du transport — Introduction à l'intégration des signaux d'avertissement critiques en termes de sécurité et de temps*

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# Foreword

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ISO/TR 12204 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 13, *Ergonomics applicable to road vehicles*.

# Introduction

This Technical Report supplements the information provided in ISO/TR 16352 “MMI of warning systems in vehicles” and specifically addresses the topic of warning signal integration in automobiles.

This Technical Report contains a mixture of general guidance information where technical consensus supports such guidance, as well as discussion of those areas where further research is required to support technical consensus. It should be noted, however, that the general guidance contained in this Technical Report is informative, rather than normative, in nature.

The HMI of warning interfaces for stand-alone active safety systems is not standardized. Recently, “Guidelines on establishing requirements for higher-priority warning signals” is being developed by the UNECE/WP29/ITS Informal Group. There are, however, many different interfaces used on production vehicles. The integration of multiple stand-alone warning systems requires consideration of basic properties of the interface such as modality, timing, and redundancy. This can lead to complex trade-offs for the system designer. It may well be that over time the industry and/or governmental regulators will converge on common specifications for warning interfaces for stand-alone warning systems.

It should also be noted that a key underlying assumption for the purposes of this Technical Report is that each of the stand-alone warning system signals to be integrated has been previously validated in terms of effectiveness and acceptability. Therefore, any changes to a particular warning signal that may be suggested by evaluating the integration of multiple warning signals into a coherent HMI are intended to address an integration issue, only, and not to compensate for any deficiency that may be present in the design of one or more underlying stand-alone warning/systems.

Poorly integrated warning signals may not be noticed or could be misunderstood, confused, or ignored and could potentially impair system performance causing the driver to respond too slowly, inappropriately or not at all. Poor integration could limit the safety benefits of the warning system.

# Road vehicles — Ergonomic aspects of transport information and control systems — Introduction to integrating safety critical and time critical warning signals

## 1 Scope

This Technical Report provides general, informative guidance for the integration of safety critical and time critical warning signals (signals which, if ignored even briefly, could result in bodily harm to the occupant(s) of the vehicle and/or to other road users) into existing in-vehicle messages presented to a driver. Integration of non-critical signals are outside the scope of this Technical Report, except to confirm that they do not affect the driver's comprehension of safety and time critical signals.

This Technical Report provides:

1) possible approaches for determining if integration is necessary to mitigate the possibility that signals from one or more vehicle system may degrade the driver's comprehension of, or response to, safety critical warning signals from another system(s); and

2) a discussion of possible methods for assessing potential integration conflicts.

It does not provide prescriptive guidance in how to design an integrated warning HMI.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Not applicable.

## 3 Terms and definitions

**3.1**
**abstract visual signal**
simple figure such as circle or square that has no clear meaning

**3.2**
**active safety warning system**
system incorporating sensors to detect potential hazards that communicate a warning signal to the driver so that a hazard may be avoided by driver intervention

**3.3**
**auditory icon**
auditory signal that represents an event or action without using verbal expression

NOTE This auditory signal can be a synthesized sound that gives the impression of a specific event or a recorded sound from everyday life.

**3.4**
**ambient noise**
sensory stimulus that is not relevant to the specific task of the driver in the vehicle's environment

NOTE This can include sound emanating from inside and outside the vehicle (auditory noise), reflection of sunlight, glare from headlights of surrounding vehicles (visual noise), and vibration from the vehicle (haptic noise).

**3.5**
**comprehensibility**
characteristic of a signal enabling the driver to understand the meaning of the signal in the context in which it is provided

**3.6**
**criticality level**
classification of severity of the collision

**3.7**
**distinguishability**
characteristic of the warning signal to be perceived by the driver when two or more signals share the same sensory mode, or are presented in close temporal within the driving environment

**3.8**
**event**
significant occurrence in the driving environment of a subject vehicle/driver

**3.9**
**human machine interface**
controls and displays that allow a human to interact with a manufactured device or system

**3.10**
**integration**
incorporation and organization of multiple devices or systems into a unified, coherent HMI, ensuring that all warning signals can be understood independently of when or how they are presented (individually or simultaneously) when present in the vehicle

**3.11**
**priority**
relative importance of two or more messages or signals

NOTE For warning signals, priority level can be obtained from criticality and urgency levels of a signal.

**3.12**
**response time**
time period from the onset of a warning signal to the point at which the driver starts to perform a vehicle control action

EXAMPLE The time from the onset of a forward vehicle collision warning system signal to when the driver starts to depress the brake pedal.

**3.13**
**safety critical signal**
signal that is intended to warn a driver in time for corrective action to be taken to prevent vehicle damage or personal injuries

NOTE There are four levels of criticality, categorized based on occupant (both in the vehicle and on the road) injury and vehicle damage defined in ISO/TS16951. The four levels are:

— Criticality level 3, severe or fatal injury to occupants;

— Criticality level 2, injury or possible injury to occupants;

— Criticality level 1, no injury to occupants but with damage to vehicle involved; and

— Criticality level 0, neither injury to occupant nor damage to any vehicle.

“Safety critical signal” defined here pertains only to criticality levels 3 and 2.

**3.14**
**scenario**
driving events and situations experienced by a driver

**3.15**
**signal**
visual, auditory, or haptic stimulus information produced by an in-vehicle system or an on-road system for the purposes of communicating driving-related information to the driver

NOTE Signals include both warning and non-warning signals.

**3.16**
**symbol**
visually perceptible figure used to convey information independently of language, produced by drawing, printing, or other means.

[ISO 2575:2010, definition 3.1]

**3.17**
**system integrator**
person(s) responsible for integration of a warning device or systems in a vehicle HMI

**3.18**
**time critical signal**
signal with high urgency level that requires driver’s response to an imminent event measurable within ten seconds

NOTE Time critical signal may or may not pertain to a warning event. There are four levels of urgency, categorized based on how fast the driver needs to respond to the warning signal. The four levels are:

— Urgency level 3, respond immediately (within zero to 3 sec);

— Urgency level 2, respond within a few seconds (3 to 10 sec);

— Urgency level 1, response preparations (take action or decision within 10 sec to 2 min);

— Urgency level 0, information only (ISO/TS 16951).

“Time critical signal” defined here pertains only to criticality level 3 and 2.

EXAMPLE Signal that informs a driver of an unsafe closing distance to an object in the vehicle’s path which requires braking or evasive steering less than 10 sec.

**3.19**
**tone**
simple sound or mixture of simple sounds with fixed frequency

NOTE Tone includes continuous sound and intermittent sound.

**3.20**
**urgency level**
classification of the time within which driver action or decision has to be taken if the benefit intended by the system is to be derived from the signal

**3.21**
**voice message**
signal with identifiable spoken terms

**3.22**
**warning event**
object, obstacle, or event in the driving environment that is likely to cause harm if ignored

**3.23**
**warning signal**
signal that is both safety critical and time critical indicating a warning event

NOTE Warning signals always pertain to risk of personal injury or death and do not include things such as navigation instructions that might also require the driver to take an action within a set time period.

# 4 Abbreviated terms

**ACC** Adaptive cruise control system

**CSW** Curve speed warning system

**FCW** Forward collision warning

**HMI** Human machine interface

**HUD** Head up display

**LCM** Lane change/merging warning system

# 5 Warning signals and situation where a warning signal is presented

## 5.1 Classification of warning signals

### 5.1.1 Background

Signals in a vehicle may communicate with the driver through auditory, visual, or haptic modalities. The signals that are candidates for integration can be classified in numerous ways, depending on which of their features are the most salient for the purposes of integration. In addition to the characteristics of signals, it is also necessary to consider the situation of the driver at the time that a given signal(s) is issued. Factors such as visibility and range of the hazard(s), e.g. other vehicle, pedestrian, roadside object, as well as necessary responses, influence how multiple warning signals should be presented. The performance characteristics that should be considered when developing an integrated HMI for multiple warning systems are classified according to the following description of warning signals and situations.

NOTE The parameters listed below are intended to identify characteristics of individual warning signals and situations in order to facilitate the identification of potential conflicts among signals. The specific values that are identified (such as the amount of response time available to the driver) have been taken from ISO/TS 16951.

### 5.1.2 Criticality

#### 5.1.2.1 Severe or fatal injury level warning signal

Warning systems that assist a driver in averting a collision that can damage the vehicle and possibly cause severe or fatal injury to the occupants.

EXAMPLE Forward collision warning that assists the driver avoiding a collision with a lead vehicle at high speed.

#### 5.1.2.2 Injury or possible injury level warning signal

Warning systems that assist a driver in averting an intermediate or low-speed collision that can damage the vehicle and possibly risk the safety of occupants.

EXAMPLE Side collision warning signal that assists the driver avoiding a vehicle (side)-to-vehicle (side) collision at intermediate or low speed.

#### 5.1.2.3 No injury (vehicle damaged) level warning signal

Warning signals that assist a driver in averting a low-speed collision that can damage the vehicle and does not risk the safety of the occupants.

EXAMPLE Back-up warning signal that assists the driver avoiding a collision with structure at low speed.

#### 5.1.2.4 No injury (no vehicle damage) level warning signals

Warning signals that assist a driver in averting a very low-speed collision that does not damage the vehicle and does not risk the safety of the occupants.

### 5.1.3 Urgency

Time within which driver action or decision has to be taken if the benefit intended by the system is to be derived from the signal (ISO/TS 16951).

#### 5.1.3.1 Respond immediately

Take immediate action or decision (within zero to three seconds) according to the presented warning signal.

EXAMPLE Obstacle immediately in the vehicle path. Brake immediately. Steer to avoid dangerous situations.

#### 5.1.3.2 Respond within a few seconds

Take action or decision according to the warning signal within 3 to 10 sec.

EXAMPLE Obstacle within a few seconds in the vehicle path. Brake in a few seconds. Steer away from danger as required.

#### 5.1.3.3 Response preparation

Prepare to take action or decision in response to the warning signal within 10 sec to 2 min.

EXAMPLE Onset of detection of an obstacle.

#### 5.1.3.4 Information Only

No direct action or decision required by the driver.

EXAMPLE System on.

### 5.1.4 Duration of signal

#### 5.1.4.1 Background

Another aspect of the temporal characteristics of a warning signal is the length of time that a signal is provided to the driver after it is initially presented.

#### 5.1.4.2 Continuous

A continuous warning signal persists until the end of the event and may provide a continuous update of the situation.

EXAMPLE Signal that indicates the driver is too close to the lead vehicle.

#### 5.1.4.3 Discrete

A discrete warning signal indicates the existence of an event but is independent of the duration of the event itself.

EXAMPLE Virtual rumble strip that lasts for a predetermined period, irrespective of whether or not the vehicle returns to the roadway.

### 5.1.5 Direction of hazard

#### 5.1.5.1 Background

Hazards may arise from any direction around the vehicle. Providing an integrated warning system requires a system integrator to consider the direction of the hazard and the likelihood that the driver has perceived it, especially when it appears in the presence of other hazards.

#### 5.1.5.2 Front of vehicle

Obstacles in the forward field of view of a driver may or may not be readily perceivable by the driver the moment his or her attention is directed to the forward road scene where the hazard has been detected by a warning system.

#### 5.1.5.3 Side of vehicle

Obstacles to the side of a vehicle may or may not be readily perceivable by the driver the moment his or her attention is directed to the side of the vehicle where the hazard has been detected by a warning system.

EXAMPLE Warning system detecting the presence of another vehicle in the driver's blind zone during an apparent attempt to merge into an adjacent lane.

#### 5.1.5.4 Rear of vehicle

Obstacles to the rear of a vehicle may or may not be readily perceivable by the driver the moment his or her attention is directed to the rear of the vehicle where the hazard has been detected by a warning system.

## 5.2 Hazard perception by drivers

### 5.2.1 Background

Warning signals are used to direct a driver's attention to hazards in the driving environment that the driver has apparently failed to perceive (or has yet to be perceived), or assess the situation appropriately, as indicated by a failure to take corrective action. The driver's failure to perceive a hazard may stem from a variety of causes, which may in turn invoke special considerations for warning system designers and integrators.

#### 5.2.2 Visible and detected by the driver

Events or situations the driver is readily able to see.

#### 5.2.3 Visible but not detected by the driver

##### 5.2.3.1 Background

Events that are not perceived by the driver, or not otherwise readily detectable from visual, haptic or audible cues. This is a situation where warning signals are to be utilized effectively to avoid hazards.

##### 5.2.3.2 Driver failed to look

Warning signals regarding events/situations that could be directly visible to the driver with a brief scan of the mirrors or a glance, but have gone undetected by the driver due to failure to attend to an area where the hazard appears.

##### 5.2.3.3 Driver looked but did not see

Warning signals provided for readily perceptible events that the driver has failed to recognize.

#### 5.2.4 Not readily perceptible to the driver

Warning signals associated with an event/situation that is not readily perceivable by the driver. This is a situation where warning signals help the driver to detect hazards.

### 5.3 Description of vehicle systems that signal the driver

#### 5.3.1 Systems requiring time critical and safety critical response

##### 5.3.1.1 Active safety vehicle dynamic system

Active safety vehicle dynamic systems can stabilize the vehicle and help prevent accidents. They incorporate sensor systems that are capable of detecting hazardous conditions of the vehicle. Various technologies are incorporated as sensors, either individually or in combination. These include sensors within the vehicle, such as yaw rate, wheel speed, and acceleration sensors that are designed to monitor the dynamics of the vehicle. A signal (usually visual) is sometimes given to the driver during activation of the system indicating the system is stabilizing the vehicle.

EXAMPLE Electronic stability control system provides automatic braking of individual vehicle wheels to assist the driver in maintaining control in critical driving situations.

##### 5.3.1.2 Driver assistance system with warning signal

A system that detects potential road hazard(s) and provides a timely warning signal to the driver.

EXAMPLE Lane departure warning system gives a warning signal when the vehicle deviates or is about to deviate the lane without the driver activating the turn signal.

NOTE Some active safety warning systems may incorporate multiple levels (or stages) of warning signals, which become progressively more urgent and safety critical. For example, ISO 17387 refers to “Level 1” and “Level 2 and above” warning signals, where “Level 2 and above” warning signals are more critical than “Level 1” warning signals.

#### 5.3.1.3 Driver assistance system with warning signal and intervention

A system that detects potential road hazard(s), provides a timely warning signal to the driver, and, if necessary, automatically manipulates vehicle control parameters to mitigate or avoid the hazard.

EXAMPLE Lane keeping system with lane departure warning that gives a warning signal when the vehicle deviates or is about to deviate outside the lane without the driver activating the turn signal and applies steering torque to help keep the vehicle inside the lane.

### 5.3.2 Systems requiring time critical, but not safety critical response

#### 5.3.2.1 Vehicle condition information system

There are numerous warning signals provided to the driver regarding the condition of the vehicle. These warning signals normally do not require immediate action of the driver even though they may require urgent attention of the driver. Although there is a possibility that the failure of the vehicle system may cause an accident (if occurring while at a high speed), warning signals about the vehicle conditions are not regarded as safety critical signals. Therefore, such warning or caution signals are not under the scope of this Technical Report.

EXAMPLE Signals indicating low fuel level, low coolant level, lamp failure, etc.

#### 5.3.2.2 Route guidance and navigation systems

Route guidance and navigation systems are special cases in that sometimes the information they present is time critical and may have implications for safety, but in other times the information presented signals a manoeuvre that is irrelevant to the immediate driving situation.

Congestion information and sharp curve warning signals provided by some navigation and route guidance systems may be safety critical and time critical, because they will be useful to avoid rear end collisions and off-road crashes, and are therefore within the scope of this Technical Report.

### 5.3.3 Systems requiring safety critical, but not time critical response

There are numerous signals provided to the driver to alert them of various abnormal vehicle conditions, some of which may lead to a hazardous condition if not attended to in a reasonable period of time. They do not, however, require immediate evasive action by the driver and, therefore, this type of signal requires a safety critical response, but not a time critical response.

EXAMPLE Signal indicating low oil pressure.

### 5.3.4 Systems requiring neither safety critical, nor time critical response

Signals from in-vehicle information systems that do not present time critical nor safety critical information to drivers are not within the scope of this Technical Report.

## 5.4 Possible driver responses

### 5.4.1 Background

The variety of responses or combination of responses by a driver to avoid the obstacle or situation identified by a warning system can be categorized as follows.

### 5.4.2 Preparation

The primary response to a perceived warning signal is to direct one's attention to a certain object or event (assumed to be a hazard/threat) and to recognize the situation. Then a driver prepares to respond by deciding on an action (typically pedal and/or steering operation).

NOTE In the case of time critical and safety critical warning signals, particularly where the hazard is apparent the moment that the driver's attention has been restored, the driver's hazard assessment and decision on how to respond may occur so rapidly that the driver is not aware of having made such an assessment and decision. This type of "pre-cognitive" response (e.g. directional orientation) may point to the need for additional testing and validation of warning design, as well as for special consideration when designing an integrated warning system that must handle the possibility that multiple time critical and safety critical warning signals may occur simultaneously or in close temporal proximity.

### 5.4.3 Responses

#### 5.4.3.1 Possible responses

Following the preparation as described above, a driver has a limited number of control actions that he or she may perform in an attempt to avoid or mitigate a crash. One or more of these responses may be appropriate in a given situation.

#### 5.4.3.2 Hard braking or acceleration

Hard braking is a driver's response that is intended to slow or stop the vehicle movement as quickly as possible. Rapid acceleration is also sometimes used by drivers to avoid an imminent collision, such as when a vehicle or object is approaching the subject vehicle from the side or the rear.

EXAMPLE An urgent warning signal from a forward vehicle collision warning system that prompts a driver braking action to avoid a frontal collision.

#### 5.4.3.3 Emergency steering manoeuvre

Emergency steering manoeuvre is intended to steer a vehicle around an object to avoid a collision.

EXAMPLE An urgent warning signal from a lane departure warning system that prompts a driver to return the vehicle to the lane.

#### 5.4.3.4 Retake control

A warning signal for the driver to retake vehicle control is associated with systems that signal the driver when he or she must resume active control from a vehicle control system. The driver is required to re-take control of the vehicle when a vehicle control system becomes inactive or exceeds its range-of-control (but prior to the advent of a particular hazard).

EXAMPLE Warning signal from an adaptive cruise control system indicating inactivation of headway sensor because of heavy rain that prompts a driver to retake control.

# 6 Discussion of integration vs. prioritization

## 6.1 Background

This clause discusses the difference between prioritization and integration and describes the relationship between them. It is important to address these two concerns individually and jointly. It would be incorrect to assume that integration concerns can be sufficiently addressed solely through prioritization.

## 6.2 Prioritization

According to ISO/TS 16951, prioritization establishes the "relative importance of two or more messages, which determines their ranking in a time sequence or emphasis of presentation." Relative importance encompasses both time urgency and safety criticality. Using these characteristics, signals can be rated from 1-n. For a higher priority warning signal, more emphasis can be given to a signal through its spatial proximity, intensity, size, modulation and duration. Signals may be shown simultaneously or in close temporal proximity. In such a case, a signal with lower priority may be suppressed to emphasize the higher priority signal.

Prioritization essentially means choosing which of the multiple warning signals is of a higher priority (e.g. more important) for the driver.

A prioritization scheme is critical when multiple warning signals are presented simultaneously or in close temporal proximity. In this situation, a decision needs to be made whether only a single warning or multiple warnings should be presented to the driver.

Signals can be prioritized using the procedures described in the following documents: ISO/TS 16951 - Procedures for determining priority of on-board messages presented to drivers (provides formal procedures and two alternative methods for determining the priority of on-board messages) and SAE J2395 - ITS In-Vehicle Message Priority (2002).

This Technical Report is not focused on prioritization of warnings, only the integration of multiple warnings into the vehicle.

## 6.3 Integration

Integration of warning signals aims to organize signals into a unified, coherent HMI. Integration encompasses including all warning signals (and systems) into the vehicle and ensuring that there are no unintended consequences such as startling or confusion of the driver. It takes into account distinguishability, comprehension, and desired response(s).

The ultimate objective of the integration process is to ensure that all warning signals can be understood independently of when or how they are presented (individually or simultaneously) when present in a single vehicle. This differs from prioritization which specifies the order, or priority, for the presentation of those warning signals.

## 6.4 Relationship of integration and prioritization

Prioritization will guide designers in establishing the relative importance of warnings. Integration will ensure a coherent interface to avoid potential conflicts leading to misperception, lack of comprehension, startling, or an inappropriate response.

Prioritization may be imposed on given information, including safety critical and non-safety critical signals, independently of designing an integrated HMI. However, without integration, warning signals could be confused even though they are prioritized. For example, two warning signals that are visually similar could be confused even though they have different prioritization. As a second example, two tones may not be easily distinguished even though they are intended to indicate different, possibly contradictory, driver responses. The tones may be presented in such close temporal proximity that the participant has trouble comprehending them, or may become startled. Or the tones may be presented in such a way that one masks the other, causing one signal to be missed by the driver.

Simply having two warning signals prioritized does not mean integration has been achieved. Prioritization produces only a ranking for the order in which warning signals should be presented. It is still possible for the warning signals to be confusing with one another, startling for the driver or for them to perceptually mask one another unless effective integration has been achieved.

In the scenario shown in Table 1, the three warning signals have triggered simultaneously. The table illustrates the differences between prioritization and integration for this situation.

**Table 1 — Example to illustrate the differences between prioritization and integration**

| | **Prioritization** | **Integration** | |
|---|---|---|---|
| **Warning signal** | **Priority** | **Modality** | **Integration issue** |
| S1 | High | Auditory: Tone Type 1 | Issue: There is a potential of tone masking if the warning signals are presented at the same time and in the same modality.<br>Possible integration action: Tones will be presented at different frequencies that avoid masking. |
| S2 | High | Auditory: Tone Type 2 | |
| S3 | Low | Visual | Issue: If the visual warning signal is not salient enough it may be ignored.<br>Integration action: Although the warning signal will likely be presented after the warning signals with higher priority, there is the danger that other visual signals may distract the driver from this warning signal. |

## 7 Issues for integration: Distinguishability and comprehensibility

### 7.1 Background

If a vehicle's warning system is designed such that its driver may receive multiple warning signals, the system designer of the vehicle should identify, early in the design process, any potential misunderstandings, confusions or conflicts among the warning signals. For the purposes of integration, the comprehensibility, distinguishability and effectiveness of stand-alone warning system signals should be established. Warning signals in an integrated HMI should be readily understood by drivers when provided in an appropriate context. If these are not resolved, driver performance in response to these warning signals may be negatively affected. In some cases, only understanding the occurrence and direction of an event may be sufficient for an appropriate response by the driver if the threat can be visually verified.

### 7.2 Distinguishability

Two or more warning signals that indicate different events and expect different responses should be capable of being separately perceived when they share the same sensory mode, or are presented in close temporal proximity. When a new warning signal is presented while another warning signal of the same priority level is already being presented, the new signal should be capable of being detected, and should be neither masked by the existing signal (i.e. should remain distinguishable) nor misunderstood as a change of state of the warning event (i.e. should be comprehensible as a new, distinct warning signal).

EXAMPLE A side collision warning system using a similar sound as a forward collision warning system may not be distinguishable.

### 7.3 Comprehensibility

Warning comprehension refers to the perceptual and cognitive process by which users interpret the meaning of in-vehicle warning signals. This process has three stages: legibility (i.e. can the driver perceive the warning signal), recognition (i.e. does the driver recognize the warning signal when it is presented among other warnings), and interpretation (i.e. does the driver understand the meaning, intent, or purpose of the warning signal). See Campbell (2004).

Specifically, warning signal comprehension likely includes the driver perceiving and understanding the meaning of the warning signal, the criticality indicated, the urgency of the situation, and the direction of the hazard.

Effort should be taken to maximize consistent use of signal characteristics with comparable safety criticality and/or urgency to avoid driver confusion and increase comprehensibility.

EXAMPLE A sound frequency and sound level used to signal a warning of high safety criticality should not be used to warn the driver that the key has been left in the ignition switch.

# 8 Situations where warning integration is needed

## 8.1 Background

When the driver is presented with multiple items of information, mental resources may be over-taxed and cognitive overload may occur [see Wickens (1992) and Green & Senders (2009)]. A driver may therefore only be able to attend to a subset of the total information presented, leaving the remaining information unprocessed. The goal of warning signals integration is to facilitate the driver's ability to discern the most important information, i.e. that which best assists in avoiding or mitigating crash risk.

Where one or more vehicle systems can provide warning signals to the driver, the system designer should identify - early in the design process - where potential conflicts between warning signals may exist. The designer should also identify potential sources of irrelevant signals and ambient noise in the vehicle, which may mask warning signals or conflict with them.

## 8.2 Warning signals sharing the same sensory modality

When two or more warning signals using the same sensory modality are presented to the driver (either simultaneously or in close temporal proximity to one another), there is the possibility that the driver can become overloaded. The primary task of every driver is to control and manoeuvre the vehicle, which is largely a visual task. If, for example, multiple warning signals are presented through the visual channel, it may be difficult or impossible for the driver to perceive the additional visual cues and to maintain visual attention to the driving environment. Similar problems can arise with auditory or haptic warnings, although the same conflict with the driving task may not exist. Specifically, if multiple warning signals are provided as auditory or haptic signals, it may also be difficult to perceive them as separate signals.

EXAMPLE 1 The presentation on an instrument cluster of an icon signalling the danger of a collision in the forward path of the vehicle might be overlooked by a driver who is concentrating on a warning indicator on the "A" pillar, which is simultaneously signalling the presence of a vehicle in the adjacent lane.

EXAMPLE 2 An auditory warning signal from a lane departure warning system and a simultaneously-presented auditory warning signal from a lane change decision aid system may conflict with or mask one another.

## 8.3 Warning signals in close spatial proximity

When two or more warning signals indicate hazards using signals provided in close spatial proximity, the driver may have difficulty distinguishing which warning signal is being indicated at a particular instant.

EXAMPLE A driver may be confused by a blind spot monitoring system warning and a lane departure warning that are co-located in the side mirror.

It should be noted that warning signals issued from different locations should still be examined for potential concerns related to other aspects of integration.

## 8.4 Warning signals with same characteristics

When two or more warning signals using the same sensory modality share certain characteristics, the driver may have difficulty distinguishing between them.

EXAMPLE A low tire pressure warning signal and the low fuel level warning signal that use similar-looking symbols may be confused with one another.

The specific signal characteristics that warrant concern will vary depending on the warning modality. For example, with visual warning signals, symbols or icons should be readily distinguishable from one another, as should warning signals presented in close spatial proximity to one another. For auditory warning signals, similar frequencies, frequency oscillations, rhythms, onset/offset rates, and speech messages could contribute to driver confusion and should be readily distinguishable from one another. For haptic warning signals, characteristics such as the location, the vibration frequency, pattern, and amplitude should be readily distinguishable from one another.

### 8.5 Frequent vs. infrequent warning signal presentation

When two warning signals can be presented at the same time, the driver may be inclined to assume the frequently-issued signal is being presented, when the less-frequently-indicated signal is actually being presented.

EXAMPLE An auditory warning signal indicating a forward collision hazard (a less frequently-indicated-signal) may be confused with an similar auditory warning signal indicating the vehicle is about to deviate the lane without the driver activating the turn signal (a more-frequently-issued-signal from lane departure warning).

### 8.6 Multiple warning signals that are presented simultaneously or in close temporal proximity

When two or more signals are communicated simultaneously or in close temporal proximity, the driver may be confused, or startled. If the different signals require different responses, the driver may also have difficulty making a decision, resulting in no action or delayed action. Finally, if the different signals require not only different, but potentially conflicting responses, the driver may be able to react to only one manoeuvre.

NOTE Some experts note that a driver facing multiple, simultaneous hazards may be unable to avoid a crash. They believe it is sufficient for a system designer to ensure that the advent of warning signals under such conditions do not in fact make things worse for a driver than they would have been in the absence of warning signal(s), e.g. by startling or confusing the driver. Other experts believe that an integrated warning HMI should provide demonstrable benefits under these conditions, and advocate testing to demonstrate that most test subjects respond appropriately to the warning signal(s), even under multiple-threat scenarios.

## 9 Tools for warning signals integration

### 9.1 Background

This section discusses several tools that may be used during system development to address potential conflicts among warning signals, or with other vehicle signals.

### 9.2 Threshold adjustment

Warning thresholds and parameters, that are used to determine when a warning signal is issued, may be updated in the presence of additional warning signals. Changing the threshold (e.g. sensitivity) could suppress lower-priority signals to allow only warning signals of a higher priority to be presented to the driver. A lower-priority signal(s) may also be completely suppressed and presented after the higher priority hazardous event (and associated warning signal) has occurred. Threshold adjustment can also be used to allow presentation of signals earlier than the timing for a single signal scenario, in order to provide the driver with extra time to understand the situation, and to execute pre-emptive or evasive action.

### 9.3 Establish modes

Designers should develop a mode of presentation for a warning signal that is compatible with its urgency and criticality, i.e. priority. For most drivers, audible signals may elicit a faster response than visual signals and should be considered for presentation of critical and urgent warning signals. Auditory signals do not require the driver's attention to be directed towards any specific location to be successfully processed. Haptic signals may also elicit a faster response than visual signals, and may not require the driver's attention to be directed towards a particular location. Therefore, auditory and haptic signals should be considered for urgent and critical warning signals where it is not certain where a driver's attention is focused. Multiple modes should be used if the direction of the driver's attention is not known, and if the warning signals are high priority.

## 9.4 Establish distinguishability

The distinguishability of two or more signals intended to be perceived by the driver as spatially or temporarily distinct may be achieved through mode allocation, changes to signal characteristics, and/or temporal management.

### 9.4.1 Spatial distinguishability

In general, signals that inform drivers of different hazardous events should be presented in different areas of a display (visual, haptic or auditory) or in different displays or modes that direct the driver's attention to the location of the hazard.

### 9.4.2 Temporal distinguishability

Warning signals that occur in close temporal proximity should be distinguishable from each other as a means of avoiding delay or confusion. Avoiding the overlap of warning signals may be the best approach to avoid overloading the same sensory channel (i.e. visual, auditory, haptic). However, if both of the warning signals presented in close temporal proximity require an immediate and different evasive action, temporal distinguishability may not be appropriate.

### 9.4.3 Distinguishability by other warning signal characteristics

Establishing distinguishability by selecting different characteristics of signals is helpful to discriminate multiple signals. For example, use of different tone or speech for audible signals is helpful in establishing distinguishability.

**Table 2 — Examples of different characteristics of signals**

| Characteristic | Description |
|---|---|
| Auditory | Pitch, frequency, waveform and volume |
| Visual | Location, flashing rate, symbol/icon design, colour, and size |
| Haptic | Amplitude, frequency, and waveform |

## 9.5 Use of common warning signals to indicate different hazards from the same direction

There is emerging evidence that the same warning signal may be used effectively to indicate different types of hazards, providing that the hazards in question are presented from the same direction (i.e. forward or lateral), and provided that the hazards in question are apparent to an alert driver once driver's attention is restored to the appropriate road scene.

The "Integrated Vehicle Based Safety System" (IVBSS) project developed an integrated light vehicle safety system incorporating FCW, LDW, LCM, and CSW systems. After evaluating various approaches, the research team of HMI experts implemented a warning signal Driver Vehicle Interface (DVI) that employed the same audible and haptic warning signals for FCW and CSW for forward warning signals, and a different, common haptic warning signal for LDW and LCM for lateral warning signals. *Post facto* visual cues were provided to differentiate between warning signals for FCW and CSW and for LDW and LCM, respectively. While this implementation was particular to the IVBSS program and the vehicles and systems used, it does suggest that shared warning signals for different systems may be acceptable and effective for light vehicles, and that the types of hazards indicated are apparent upon visual conformation. See DOT HS 810 905 (2008).

## 10 Identification and evaluation methods

### 10.1 Background

This clause gives a brief discussion of three proposed integration evaluation procedures contained in informative annexes to this document. It should be emphasized that each of the methodologies discussed in this paper currently are not intended as a replacement to on-road, empirical research that examines responses in specific situations. Rather, when they are applied, they should be applied with caution and only as a means of complimenting on-road, empirical research that should be conducted.

The vehicle HMI should be tested to ensure effective integration for all warning signals. The HMI of a warning system should not be the cause of unintended consequences, such as startling or confusing the driver. The driver should be able to quickly understand and assess a hazard and respond appropriately. In most instances, warning signals are used to inform the driver of a situation that he or she does not perceive. If the driver is already aware of the situation, then the warning signal should not interfere with an appropriate decision/response. If the driver is not aware of the situation, then the warning signal should be comprehended and clearly distinguished from any other signals.

The following provides a brief description of each method.

### 10.2 Procedure to identify integration needs

A procedure for identifying integration needs is described in Informative Annex A. A discussion of the strengths and weaknesses of the procedure is also provided in Annex A.

This procedure describes an analytical process for evaluating the potential for integration conflicts to occur by considering all signals in a given vehicle HMI in a systematic format. First, all signals are examined for distinguishability among one another. Second, a systematic analysis method is conducted to identify which safety critical signs may occur at the same time according to system functioning.

### 10.3 Timely Comprehension Method

A method for testing the "timely comprehension" by drivers of warning signals is provided in Annex B. A discussion of the strengths and weaknesses of this method is also provided in Annex B.

Timely Comprehension is a laboratory methodology used to evaluate integrated warning systems in development. This methodology can help identify comprehension/distinguishability issues prior to full system development. Timely Comprehension is based on the premise that each warning signal presented in the vehicle should be comprehended and clearly distinguished from other warning signals in an integrated context.

### 10.4 Appropriate Response Method

A method for testing "appropriate response" by drivers to multiple warning signals presented simultaneously in multiple hazard situations is provided in Annex C. A discussion of the strengths and weaknesses of this method is also provided in Annex C.

This method uses a driving simulator or a testing vehicle to identify an integration issue that results in degradation of the effectiveness of the multiple warning signals (e.g. inappropriate response) when presented simultaneously or in close temporal proximity.

# Annex A
(informative)

# Procedure for assessing integration needs

NOTE The information contained in this Annex describes a method of identifying integration needs for two or more warning signals/signals. Work is ongoing to validate this procedure. However, at this time, the method described herein does not maintain full technical consensus among safety and human factors experts.

## A.1 Introduction

In certain driving scenarios, a driver is presented with multiple warning signals, potentially in the same modality or close temporal proximity. To ensure distinguishability and comprehensibility potentially conflicting signals need to be integrated. When new safety warning signals are introduced into existing vehicle HMI, a designer needs to systematically review the new warning signals.

Testing all warning pairs and combinations experimentally for conflict is not feasible because of the sheer number of warning signals. A procedure is introduced for identifying potential conflicts while maintaining a manageable workload. In this Annex, a series of tables are used to guide and structure the conflict review process.

The integration procedure introduced in this Annex provides guidance with regard to checking a new or redesigned warning signal for its distinguishability and comprehensibility against existing signals.

## A.2 Advantages

When a step by step procedure to assess an integration need is established, users can follow the procedure to discover integration conflicts. If all variables in the procedure are defined clearly, the procedure can be performed by computer software which reduces time for the warning integration.

NOTE Software to conduct the method described in A.6, A.7.2 and A.7.4. is available at ISO website (http://standards.iso.org/iso/12204/)

## A.3 Limitations

The number of steps in the procedure is numerous when all warning signals of various installed active safety warning systems are taken into consideration. Therefore, criteria are introduced to help limit the number of warning signals to be examined at one time. Although the criteria introduced here has rationality, it is not yet experimentally been proven valid.

When creating the procedure, warning signals under investigation are based on current active safety technologies. Modality, presentation, and content of warning make these technologies state of the art, However, novel type warning signals that are beyond our assumption will emerge in the future. Therefore, the procedure provided may or may not work on future warning signals.

## A.4 Procedure organization

In this annex, procedures to identify distinguishability and comprehensibility conflicts are introduced. Two methods of identifying safety critical and time critical signals for which simultaneous presentation is possible are described for comprehensibility conflict. Method 1 is to construct a matrix to identify possible pairs of the signals to be presented (A.6.2). This is a method that can be applied for cases in which only two warning signals could be presented. For cases in which three or more signals are presented simultaneously, it is necessary to further examine combined signal pairs. Method 2 examines two or more warning signals under specified conditions (A.6.3). It can cover various situations and is not limited with two warning signals. However, this method is an iterative, rather than a stepwise, procedure. Table A.1 provides an overview of the procedure with both alternatives.

**Table A.1 — Comparison of the two methods**

<table>
<tr><th colspan="2">A.6 Distinguishability conflict identification procedure</th></tr>
<tr><td colspan="2">A.6.2 Auditory signal distinguishability analysis<br>A.6.3 Visual signal distinguishability analysis</td></tr>
<tr><th colspan="2">A.7 Comprehensibility conflict identification and integration</th></tr>
<tr><td colspan="2">A.7.2 Selection of urgent/critical signals<br>A.7.2.1 Warning signals criticality categorization<br>A.7.2.2 Warning signals urgency categorization</td></tr>
<tr><td>A.7.3 Matrix method<br>(Alternative 1)<br>A.7.3.1 Developing of matrix<br>A.7.3.2 Scenario evaluation (warning signal pairs)</td><td>A.7.4 System functioning conflict method<br>(Alternative 2)<br>A.7.4.1 System function conflict table<br>A.7.4.2 Scenario creation (warning signal sets)</td></tr>
</table>

## A.5 “Conflict identification example” used to illustrate the procedure

The following example is used to demonstrate the procedures of auditory and visual signal analysis in subclauses A.6.2, A.6.3 and A.7. The examples given in this Annex only serve the purpose of illustrating the guidelines. The classification of the warning signals and information given to the driver is to be specified by the designer.

Suppose that a system designer plans to introduce

— a Lane Departure Warning and

— a Forward Collision Warning

into the vehicle with existing signals as

— a Parking aid

— a Blind Spot Monitoring system and

— an Advanced Cruise Control.

This vehicle also included standard system as

— Seat belt minder

— Rollover stability

— Door open

— Low oil pressure

— Engine over temperature

— Water in fuel

— Tire pressure.

In this example, the Seat belt minder emits a bell sound (B1) and displays a symbol (I1) in the instrument cluster when a seat belt is not latched.

“Rollover stability fault” displays a visual symbol of “Rollover stability fault” (I2) in the instrument cluster anytime a fault in the rollover is detected.

“Door open” gives a bell sound (B1) and displays a visual symbol of “open door” (I3) in the instrument cluster when a door is open.

“Low oil pressure fault” has two levels of warnings. The first one is informational and displays only an icon “Low oil pressure“ (I4) on the instrument cluster. When the pressure becomes too low, the second level is urgent. The system emits a tone (B1) and displays the same visual message in the instrument cluster.

“Engine over temperature fault” also has two levels of warnings. The first one is informational and displays an icon “engine temperature“ (I5) on the instrument cluster. When the temperature becomes too high, the second level is urgent. The system emits a tone (B1) and displays the same visual message in the instrument cluster.

“Water in fuel” displays visual written characters of “Water in fuel” (C1) in the instrument cluster when a fault is detected.

“Tire pressure fault” has two levels of warnings. The first one is informational and displays an icon “tire pressure fault“ (I6) on the instrument cluster. When the pressure becomes too low, the second level is urgent, the system emits a higher tone (B2) and displays the same visual message in the instrument cluster.

The existing Blind Spot Warning system displays a flashing light on the relevant pillar (left or right, V1) when another vehicle is present in the blind spot (left or right) in driving situations.

The existing Parking aid system emits a continuous horn sound (auditory icon, A3) when the vehicle moves slowly and is approaching another vehicle in all situations (driving or reverse). When the horn sound is given, an icon “Parking aid” (I7) is also displayed in the instrument cluster.

The existing Advanced Cruise Control system displays an informative message (C2) on the centre screen if cruise control doesn't work. It emits a continuous horn tone (auditory icon, A3) and displays a red symbol (I8), if it is not able to manage the situation with the front-of vehicle in driving situations (“ACC overload”).

The new Forward Collision Warning system is designed to generate a repeated short horn sound (auditory icon, A1), and displays a yellow symbol (I9) on a HUD when a forward object is within the level 1 zone. This system has a repeated long horn sound (auditory icon, A2), and displays a red symbol (I10) that is the same as “ACC overload” on the HUD when the object is within the level 2 zone.

The new Lane Departure Warning produces a beep sound (B5) and lights a LED lamp (V2) on the A pillar on the same side when the outside of one of the front wheels is within the warning threshold.

All of these messages can be found in Table A.2.

**Table A.2 — Example of signals used to explain the procedure**

| | | | Auditory | | | Visual | | |
|---|---|---|---|---|---|---|---|---|
| **Id** | **Status** | **Description** | **Expected direction of attention** | **Auditory category** | **Name** | **Location visual signal** | **Visual category** | **Name** |
| S1 | - | SEAT BELT MINDER | Instrument Cluster | Tone | B1 | Instrument Cluster | Symbol | I1 |
| S2 | - | ROLLOVER STABILITY FAULT | - | - | | Instrument Cluster | Symbol | I2 |
| S3 | - | DOOR OPEN | Instrument Cluster | Tone | B1 | Instrument Cluster | Symbol | I3 |
| S4a | - | LOW OIL PRESSURE (information) | - | - | | Instrument Cluster | Symbol | I4 |
| S4b | - | LOW OIL PRESSURE (urgent) | Instrument Cluster | Tone | B1 | Instrument Cluster | Symbol | I5 |
| S5a | - | ENGINE OVERTEMP (information) | - | - | | Instrument Cluster | Symbol | I6 |
| S5b | - | ENGINE OVERTEMP (urgent) | Instrument Cluster | Tone | B1 | Instrument Cluster | Symbol | I7 |
| S6 | - | WATER IN FUEL | - | - | | Instrument Cluster | Character | C1 |
| S7a | - | TIRE PRESSURE MONITORING (info) | - | - | | Instrument Cluster | Symbol | I8 |
| S7b | - | TIRE PRESSURE MONITORING (urgent) | Instrument Cluster | Tone | B2 | Instrument Cluster | Symbol | I8 |
| S8r | - | BLIND SPOT DETECTION right | - | - | | Right Pillar | Abstract | V1 |
| S8l | - | BLIND SPOT DETECTION left | - | - | | Left Pillar | Abstract | V1 |
| S9 | - | PARKING AID ALERT | Rear Road Scene | Auditory Icon | A3 | Instrument Cluster | Symbol | I9 |
| S10a | - | ADAPTIVE CRUISE CONTROL FAULT | - | - | | Centre Screen | Character | C2 |
| S10b | - | ACC CAPACITY OVERLOAD | Forward Road Scene | Auditory Icon | A3 | Centre Screen | Symbol | I10 |
| S11a | New | FORWARD COLLISION WARNING (CAUTION) | Forward Road Scene | Auditory Icon | A1 | HUD | Symbol | I11 |
| S11b | New | FORWARD COLLISION WARNING (IMMINENT) | Forward Road Scene | Auditory Icon | A2 | HUD | Symbol | I10 |
| S12r | New | LANE DEPARTURE left | Right Road Scene | Tone | B5 | Right Pillar | Abstract | V2 |
| S12l | New | LANE DEPARTURE right | Left Road Scene | Tone | B5 | Left Pillar | Abstract | V2 |

## A.6 Distinguishability conflict identification procedure

### A.6.1 Attention direction, spatial location, and warning signal characteristics

#### A.6.1.1 Objective

The goal of this step is to identify conflicts due to display mode. The objective is to ensure that safety critical signals will not be confused with other safety critical or non-safety critical signals that indicate a different type of hazard.

EXAMPLE 1 A sound signal used by a collision warning device and a sound signal used for in-coming phone call. The phone call signal will occur more often than the collision warning, and is thus more familiar to the driver. In this case, if the sound for the collision warning is similar to that for a phone call, the driver may confuse the collision warning signal for the phone call signal.

EXAMPLE 2 Given separate warning signals for forward collision and blind spot monitoring, the first warning signal intends to draw driver's attention to the area in front of the vehicle while the second one to the left or right side of the vehicle. If the two warning signals have similar characteristics the driver may be confused about the nature and location of the hazard.

#### A.6.1.2 Signals to be processed

Since existing signals should have already been tested for distinguishability, the test procedure using test participants should be applied when a new or redesigned warning signal is introduced to ensure that the new signal is distinguished from existing signals.

In A.5 “Conflict identification example” is used to illustrate the procedure, warning signals from the Lane Departure Warning and Forward Collision Warning systems should be tested with other existing signals to ensure that the new signal is distinguishable from the existing signals.

#### A.6.1.3 Auditory and visual parts of signals

Furthermore, when a warning signal is designed using two or more different modes, each mode should be distinguishable from any other signal in that mode. For example, if message “A” is composed of a beep and a symbol, and message “B” is composed of a beep and an icon, the two beeps should be included in the auditory analysis and the two visual parts (symbol and icon) should be included in the visual analysis.

The following clauses describe the procedure for identifying modal conflicts of visual and auditory warning signals.

### A.6.2 Auditory signal distinguishability analysis

Two conditions need to be met before it is necessary to test an auditory warning signal for distinguishability against one or more existing auditory signals: First, the signal is intended to draw the driver’s attention to a different location from an existing signal(s). During driving, a driver’s attention usually focuses on the instrument cluster, forward road scene, left road scene, right road scene, rear road scene, and centre console. Second, the signal should share the same auditory property with the existing signal(s). Properties of auditory warning signals can be categorized into “tone”, “auditory icon”, and “voice message”.

**Table A.3 — Example of auditory modalities of signals**

| | | Expected Direction of attention | Instrument Cluster | | | Forward Road Scene | | | Left Road Scene | | | Right Road Scene | | | Rear Road Scene | | | Centre console | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Auditory Category | Tone | Auditory Icon | Voice | Tone | Auditory Icon | Voice | Tone | Auditory Icon | Voice | Tone | Auditory Icon | Voice | Tone | Auditory Icon | Voice | Tone | Auditory Icon | Voice |
| S1 | - | SEAT BELT MINDER | X | | | | | | | | | | | | | | | | | |
| S3 | - | DOOR OPEN | X | | | | | | | | | | | | | | | | | |
| S4b | - | LOW OIL PRESSURE (urgent) | X | | | | | | | | | | | | | | | | | |
| S5b | - | ENGINE OVERTEMP (urgent) | X | | | | | | | | | | | | | | | | | |
| S7b | - | TIRE PRESSURE MONITORING (urgent) | X | | | | | | | | | | | | | | | | | |
| S9 | - | PARKING AID ALERT | | | | | | | | | | | | | | X | | | | |
| S10b | - | ACC CAPACITY OVERLOAD | | | | | X | | | | | | | | | | | | | |
| S11a | New | FORWARD COLLISION WARNING (CAUTION) | | | | | X | | | | | | | | | | | | | |
| S11b | New | FORWARD COLLISION WARNING (IMMINENT) | | | | | X | | | | | | | | | | | | | |
| S12r | New | LANE DEPARTURE right | | | | | | | X | | | | | | | | | | | |
| S12l | New | LANE DEPARTURE left | | | | | | | | | | X | | | | | | | | |

The auditory signals described in A.5 are listed in Table A.3. The intended location of attention for S1, S3, S4b, S5b, and S7b is the instrument cluster. For S12r and S12l the location is to the left or right of the subject vehicle. S9 is located near the rear road scene and for S10b, S11a and S11b the front road scene of the subject vehicle. Warning signals, S1, S3, S4b, S5b, S7b S12r and S12l, produce either a bell, chime, or beep sound. These sounds are categorized as "tones". Warning signal S9, S10b, S11a and S11b make a horn sound, these sounds are categorized as "auditory icon".

**Table A.4 — Example of auditory mode potential conflict identification table**

| Id | Name | Description | S1 | S3 | S4b | S5b | S7b | S9 | S10b | S11a | S11b | S12r | S12l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S11a | A1 | FORWARD COLLISION WARN (CAUTION) | C | C | C | C | C | A3 | D | | D | C | C |
| S11b | A2 | FORWARD COLLISION WARN (IMMINENT) | C | C | C | C | C | A3 | D | D | | C | C |
| S12r | B5 | LANE DEPARTURE right | B1 | B1 | B1 | B1 | B2 | C | C | C | C | | B5 |
| S12l | B6 | LANE DEPARTURE left | B1 | B1 | B1 | B1 | B2 | C | C | C | C | B5 | |
| | | Legend | | | | | | | | | | | |
| | D | NO conflict: same location of attention direction | | | | | | | | | | | |
| | C | NO conflict: different location of attention direction but different characteristic | | | | | | | | | | | |
| | X | CONFLICT: different location of attention direction and same characteristic | | | | | | | | | | | |

In the example, it is necessary to test for distinguishability between the new auditory signals B5 (S12r and S12l) and the existing auditory signals B1 (S1, S3, S4b, and S5b) and B2 (S7b), because the new auditory signals draw the driver's attention in different directions (instrument cluster versus left or right road scene). No tests are needed between signals B5 (S12r and S12l) and the existing auditory signals for S9, S10b, S11a, and S11b, because the auditory categories are different (Tone versus Auditory Icon) and the signals will not be confusing. It could be necessary to test the distinguishability between B5 (S12r) and B6 (S12l) but this test concerns the same system (Lane Departure Warning) and has to be done previously during system design. It is a design system problem and not an integration problem.

Also, it is necessary to test for distinguishability based on a shared property, because S11a and S11b use an "auditory icon", as do S9 also. The auditory categories are different between signals A1 and A2 and the existing auditory signals for S1, S3, S4b, S5b, S7b, S12r, S12l, thus tests are not needed. No tests are needed between FCW signals (S11a and S11b) and ACC signal (S10b) because they draw the driver's attention in the same direction (Forward road scene).

### A.6.3 Visual signal distinguishability analysis

Two conditions need to be met before it is necessary to test a visual warning signal for distinguishability against one or more existing visual signals: First, the new warning signal is displayed in the same location as (or very close to) an existing signal(s). Second, the new signal shares the same visual property as the existing signal(s). Locations of visual signals usually include instrument cluster, centre console, left and right A pillar, left and right rear view mirror, centre rear view mirror, and a HUD. Properties of visual warning signals can be categorized into "abstract visual signal", "symbol" and "written character".

**Table A.5 — Example of visual modalities of signals**

| | | Location of visual signal | Instrument Cluster | | | Centre Screen | | | Left Pillar | | | Right Pillar | | | HUD | | | … | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Visual Category | Abstract | Symbol | Character | Abstract | Symbol | Character | Abstract | Symbol | Character | Abstract | Symbol | Character | Abstract | Symbol | Character | Abstract | Symbol | Character |
| S1 | - | SEAT BELT MINDER | | X | | | | | | | | | | | | | | | | |
| S2 | - | ROLLOVER STABILITY FAULT | | X | | | | | | | | | | | | | | | | |
| S3 | - | DOOR OPEN | | X | | | | | | | | | | | | | | | | |
| S4a | - | LOW OIL PRESSURE (information) | | X | | | | | | | | | | | | | | | | |
| S4b | - | LOW OIL PRESSURE (urgent) | | X | | | | | | | | | | | | | | | | |
| S5a | - | ENGINE OVERTEMP (information) | | X | | | | | | | | | | | | | | | | |
| S5b | - | ENGINE OVERTEMP (urgent) | | X | | | | | | | | | | | | | | | | |
| S6 | - | WATER IN FUEL | | | X | | | | | | | | | | | | | | | |
| S7a | - | TIRE PRESSURE MONITORING (info) | | X | | | | | | | | | | | | | | | | |
| S7b | - | TIRE PRESSURE MONITORING (urg) | | X | | | | | | | | | | | | | | | | |
| S8r | - | BLIND SPOT DETECTION right | | | | | | | | | | X | | | | | | | | |
| S8l | - | BLIND SPOT DETECTION left | | | | | | | X | | | | | | | | | | | |
| S9 | - | PARKING AID ALERT | | X | | | | | | | | | | | | | | | | |
| S10a | - | ADAPTIVE CRUISE CONTROL FAULT | | | | | | X | | | | | | | | | | | | |
| S10b | - | ACC CAPACITY OVERLOAD | | | | | X | | | | | | | | | | | | | |
| S11a | New | FORWARD COLLISION W (CAUTION) | | | | | | | | | | | | | | X | | | | |
| S11b | New | FORWARD COLLISION W (IMMINENT) | | | | | | | | | | | | | | X | | | | |
| S12r | New | LANE DEPARTURE right | | | | | | | | | | X | | | | | | | | |
| S12l | New | LANE DEPARTURE left | | | | | | | X | | | | | | | | | | | |

Using the example described in A.5, the location of most of the signals is the instrument cluster, except for Blind Spot signals (S8r, S8l) and the lane departure warning (S12r, S12l) on the pillars, to ACC on the central screen and forward collision warning on the HUD. The physical property of the signals is “symbol”. "Abstract" is used for land departure warnings and blind spot signals.

**Table A.6 — Example of visual mode potential conflict identification table**

| Id | | Description | S1 | S2 | S3 | S4<br>a | S4<br>b | S5<br>a | S5<br>b | S6 | S7<br>a | S7<br>b | S8<br>r | S8<br>l | S9 | S1<br>0a | S1<br>0b | S1<br>1a | S1<br>1b | S1<br>2a | S1<br>2b |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S11a | I11 | FCW (CAUTION) | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | | I10 | D | D |
| S11b | I10 | FCW (IMMINENT) | D | D | D | D | D | D | D | D | D | D | D | D | D | D | D | I11 | | D | D |
| S12r | V2 | LDW right | D | D | D | D | D | D | D | D | D | D | V1 | D | D | D | D | D | D | | D |
| S12l | V2 | LDW left | D | D | D | D | D | D | D | D | D | D | D | V1 | D | D | D | D | D | D | |
| | | Legend | | | | | | | | | | | | | | | | | | | |
| | D | NO conflict different Location of signal | | | | | | | | | | | | | | | | | | | |
| | C | NO conflict same Location of signal but different characteristic | | | | | | | | | | | | | | | | | | | |
| | X | CONFLICT same Location of signal and same characteristic | | | | | | | | | | | | | | | | | | | |

The distinguishability test is required between S11a and S11b because both are displayed in the same location (HUD) and both signals (I11 and I10) are categorized as “symbols”, thereby meeting the two conditions for distinguishability test. This distinguishability is needed to ensure the comprehension of the level of urgency of the situation by the driver.

The distinguishability test is also required between S12r and S8r because both are displayed in the left pillar. It should also be used on S12l and S8l because both are displayed in the right pillar. The signals (V1 and V2) are categorized as “abstract”, thereby meeting the two conditions for distinguishability test. This distinguishability is needed to ensure the comprehension of the situation by the driver (lane departure problem or blind spot detection).

## A.7 Comprehensibility conflict identification and integration

### A.7.1 Background

This procedure includes several steps. The first step is to determine the criticality of all warning signals with the exception of non-safety critical warning signals. The second step is to determine the urgency of all warning signals, excluding non-time critical warning signals. The third step is to identify signals that are both safety critical and time critical. These are the signals that need to be examined for comprehensibility. Signals that are both safety critical and time critical are compared under driving scenarios with different driving conditions to determine which signals need to be integrated.

### A.7.2 Selection of urgent/critical signals

#### A.7.2.1 Warning signals criticality categorization

Continuing with the example described in A.5, Table A.7 categorizes all warning signals into three categories: safety critical signals to prevent injury, critical signals to prevent vehicle damage and non-safety critical signals. “Injury and damage level" includes both “Severe and fatal injury level warning signal” and “Injury or possible injury level warning signal”. “Damage level” corresponds to “no injury (vehicle damaged level warning signal” (see 5.1.2). Only the safety critical signals (“Injury and Damaged level” and “Damage level”) will be retained for the next step. Non-safety critical signals will be dropped from the procedure.

**Table A.7 — Example of criticality categorization table**

| | | | Injury and damage level | Damage level | Non safety related |
|---|---|---|---|---|---|
| S1 | - | SEAT BELT MINDER | | | X |
| S2 | - | ROLLOVER STABILITY FAULT | | | X |
| S3 | - | DOOR AJAR | | | X |
| S4a | - | LOW OIL PRESSURE (information) | | | X |
| S4b | - | LOW OIL PRESSURE (urgent) | | X | |
| S5a | - | ENGINE OVERTEMP (information) | | | X |
| S5b | - | ENGINE OVERTEMP (urgent) | | X | |
| S6 | - | WATER IN FUEL | | | X |
| S7a | - | TIRE PRESSURE MONITORING (information) | | | X |
| S7b | - | TIRE PRESSURE MONITORING (urgent) | | X | |
| S8r | - | BLIND SPOT DETECTION right | X | | |
| S8l | - | BLIND SPOT DETECTION left | X | | |
| S9 | - | PARKING AID ALERT | | X | |
| S10a | - | ADAPTIVE CRUISE CONTROL FAULT | | | X |
| S10b | - | ACC CAPACITY OVERLOAD | X | | |
| S11a | New | FORWARD COLLISION WARNING (CAUTION) | X | | |
| S11b | New | FORWARD COLLISION WARNING (IMMINENT) | X | | |
| S12r | New | LANE DEPARTURE right | X | | |
| S12l | New | LANE DEPARTURE left | X | | |

In this example, the warnings S8l, S8r, S10b, S11a, S11b, S12r and S12l are safety critical signals which can avoid injuries. The warnings S4b, S5b, S7b, and S9 are safety critical signals which can avoid vehicle damage and possibly avoid occupant's damage. They will be carried over to the next step for urgency categorization. The signals S1, S2, S3, S4a, S5a, S6 and S7a are non-safety related signals and will be removed from the process.

### A.7.2.2 Warning signals urgency categorization

In this step, safety critical warning signals from the criticality categorization step (Table A.7) are entered into four urgency categories, time critical signals requiring an immediate response or response within a few seconds and non-time critical signals requiring preparation or no response. Only those signals that are identified as safety critical and time critical from the table are retained for the next step. The first group contains the messages “Injury and damage level” with “Response immediately”. The second group contains the messages “Injury and damage level” with “Response within a few seconds” and “Damage level” with “Response immediately”.

**Table A.8 — Example of urgency categorization table**

| | | | Response immediately | Response within a few seconds | Response preparation | Information only |
|---|---|---|---|---|---|---|
| | | Mandatory no-safety related signals | | | | |
| S1 | Mandatory | SEAT BELT MINDER | | | | X |
| | | "Injury and damage level" signals to avoid injury | | | | |
| S8r | - | BLIND SPOT DETECTION right | | L2 | | |
| S8l | - | BLIND SPOT DETECTION left | | L2 | | |
| S10b | - | ACC CAPACITY OVERLOAD | L1 | | | |
| S11a | New | FORWARD COLLISION WARNING (CAUTION) | | L2 | | |
| S11b | New | FORWARD COLLISION WARNING (IMMINENT) | L1 | | | |
| S12r | New | LANE DEPARTURE right | | L2 | | |
| S12l | New | LANE DEPARTURE left | | L2 | | |
| | | "Damage level" signals to avoid vehicle damage | | | | |
| S4b | - | LOW OIL PRESSURE (urgent) | | | X | |
| S5b | - | ENGINE OVERTEMP (urgent) | | X | | |
| S7b | - | TIRE PRESSURE MONITORING (urgent) | L2 | | | |
| S9 | - | PARKING AID ALERT | L2 | | | |

After Table A.7 and A.8, a set of signals that are both safety critical and time critical are identified. In the example, the identified signals in the first group are S10b, S11b, S7b, S9 and the second group contains S8r, S8l, S11a, S12r, S12l, S7b and S9. The mandatory signals have to be taken into account in the two groups.

## A.7.3 Matrix method to identify safety critical and time critical signals that might be presented simultaneously and integration (Alternative 1)

### A.7.3.1 Development of the matrix

The matrix method is basically the same method described in Annex G in ISO/TS 16951. Priorities are not determined by numerical values of criticality and urgency but by pair comparison of the different warning signals. Criticality and urgency are considered by this comparison but there is no need to assign numerical values to the different warnings.

The matrix now lists the set of safety and time critical warning signals that have the potential to cause comprehensibility conflicts. Table A.9 shows the signals identified from the example. In the matrix, pairs like "S11a and S9", "S11b and S8r", "or "S12r and S9" are identified.

Since this step aims only to integrate new warnings only a part of the matrix is needed. All columns with the already existing warning signals can be omitted, since the content has been developed in a previous integration process.

**Table A.9 — Example of matrix**

| | | | S11a | S11b | S12r | S12l |
|---|---|---|---|---|---|---|
| S1 | Mandatory | SEAT BELT MINDER | ss | ss | ss | ss |
| S8r | - | BLIND SPOT DETECTION right | dm | dm | dm | dm |
| S8l | - | BLIND SPOT DETECTION left | dm | dm | dm | dm |
| S10b | - | ACC CAPACITY OVERLOAD | ss | ss | dm | dm |
| S11a | New | FORWARD COLLISION WARNING (CAUTION) | - | | | |
| S11b | New | FORWARD COLLISION WARNING (IMMINENT) | me | - | | |
| S12r | New | LANE DEPARTURE right | ss | ss | - | |
| S12l | New | LANE DEPARTURE left | ss | ss | me | - |
| S7b | - | TIRE PRESSURE MONITORING (urgent) | R | R | R | R |
| S9 | - | PARKING AID ALERT | me1 | me1 | me1 | me1 |

Explanation

For some of the situations, the prioritization and integration is obvious and identified by the following terms. No detailed scenario description is needed.

dm The warning signals are presented on different modalities and it has been verified that they don’t interfere. They can be presented simultaneously.

L The function in the line is more important, so the warning signal of the row is suppressed in all driving situations.

R The function in the row is more important, so the warning signal of the line is suppressed in all driving situations.

me Mutually exclusive.

me1 Mutually exclusive since the two systems work in different speed ranges.

ss See scenario. The situations are complicated, so a scenario description is needed for the determination of prioritization and integration.

The importance of a warning signal is decided by the criticality level. When a pair includes a signal with “Damage and injury level" and a signal with “Damage level", the latter is suppressed.

Mutually exclusive signals are presented under exclusive conditions of system functioning parameters from the same system. Since they are under control of a system, the signals cannot be presented simultaneously. System functioning parameters where there is possibility to present signals is shown in Table A.10. S9 from parking aide alert is given when the gear is in reverse and below 40 mph. The new systems which give signals, S11a, S11b, S12r and S12l, are activated under the conditions of above 40mph and in drive gear position. Therefore, they are exclusive both in speed range and gear position and cannot be presented simultaneously.

**Table A.10 — Example of list of conditions for presenting the warning signals**

| | | System functioning parameters | Gear | | Speed | | Deviation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Conditions | Reverse | Drive | < 40 mph | >=40 mph | Right Deviation | Left Deviation | Any |
| S1 | Mandatory | SEAT BELT MINDER | X | X | X | X | X | X | X |
| S8r | - | BLIND SPOT DETECTION right | X | X | X | X | X | | |
| S8l | - | BLIND SPOT DETECTION left | X | X | X | X | | X | |
| S10b | - | ACC CAPACITY OVERLOAD | | X | | X | X | X | X |
| S11a | New | FORWARD COLLISION WARNING (CAUTION) | | X | | X | X | X | X |
| S11b | New | FORWARD COLLISION WARNING (IMMINENT) | | X | | X | X | X | X |
| S12r | New | LANE DEPARTURE right | | X | | X | | X | |
| S12l | New | LANE DEPARTURE left | | X | | X | | X | |
| S4b | - | LOW OIL PRESSURE (urgent) | X | X | X | X | X | X | X |
| S5b | - | ENGINE OVERTEMP (urgent) | X | X | X | X | X | X | X |
| S7b | - | TIRE PRESSURE MONITORING (urgent) | X | X | X | X | X | X | X |
| S9 | - | PARKING AID ALERT | X | | X | | X | X | X |

Since two signals for the pairs for “dm”, “me” and “me1” are not presented simultaneously, there is not a need to test their comprehensibility. For signal pairs for “L” and “R”, one can be suppressed logically in order to convey information from the clearly more important signal. If a system designer decided not to suppress one of them, the pair can be regarded as “ss”. Signals of the pairs assigned as “ss” have the possibility to be presented simultaneously, and can be examined comprehensibly using a scenario description. Examples are shown in A.7.3.2.

### A.7.3.2 Scenario description and integration solution

A scenario description in this context defines a detailed driving situation where multiple warning signals might be presented simultaneously. Each scenario description includes traffic context, road condition, vehicle dynamics, driver’s manoeuvre, and strategy for signal presentation. The description can be specified by selecting among the various conditions under which warning signals are presented.

Each signal pair in Alternative 1 should be tested using a scenario description. A warning signal integration solution should be determined by the group of experts for each scenario. If several scenarios are addressed, compatibility among integration solutions should also be verified.

### A.7.3.3 Examples of the scenario description when signal pairs are presented simultaneously and its integration solution

**Table A.11 — Example of scenario description for seat belt minder (S1) and forward collision warning (S11a or S11b)**

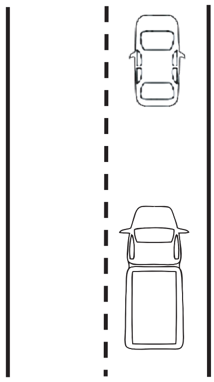
| | |
|---|---|
| **Road context**  | Road:<br>• Road structure =one or more lanes<br><br>Traffic description:<br>• One vehicle in front within caution zone<br><br>Weather:<br>• all conditions |
| **Vehicle dynamic** | Above 50 km/h |
| **Driver's current manoeuvre** | The driver keeps the lane at a constant speed higher than that of the lead vehicle while trying to latch the seat belt. |
| **Warning signals** | "S1: SEAT BELT REMINDER" is kept issuing since the seat belt has been unlatched.<br><br>FORWARD COLLISION WARNING (S11a: caution or S11b: imminent) is issued when a forward vehicle enters within the warning zone. |
| **Possible integration solution** | Forward collision warning is more urgent. Seat belt reminder is suppressed. Seat belt reminder is reissued after the vehicle reaches sufficient headway. |

**Table A.12 — Example of scenario description for ACC Overload (S10b) and forward collision warning (S11a or S11b)**

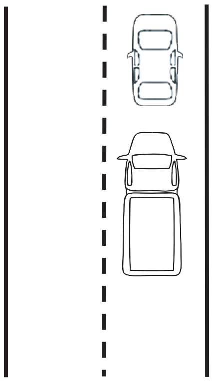
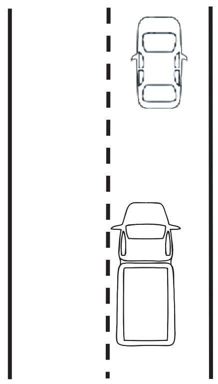
| | |
|---|---|
| **Road context**  | Road:<br>• Road structure =one or more lanes<br><br>Traffic description:<br>• One vehicle in front within warning zone<br><br>Weather:<br>• all conditions |
| **Vehicle dynamic** | Above 30 km/h. |
| **Driver's current manoeuvre** | The driver keeps the lane at a speed much higher than that of the lead vehicle. |
| **Warning signals** | FORWARD COLLISION WARNING (S11a: caution or S11b: imminent) is issued when a forward vehicle enters within the caution zone and the ACC capacity is not sufficient (S10b). |
| **Possible integration solution** | This needs a determination of warning levels depending on the speed of both cars and the capacity of ACC. The warning presentation can be the same for ACC overload and collision. |

**Table A.13 — Example of scenario description for Lane Departure (S12r or S12l) and Forward collision warning (S11a or S11b)**

| | |
|---|---|
| **Road context**  | Road:<br>• Road structure =one or more lanes<br><br>Traffic description:<br>• One vehicle forward is within warning zone<br><br>Weather:<br>• all conditions |
| **Vehicle dynamic** | Above 30 km//h. |
| **Driver's current manoeuvre** | The driver keeps the lane at a constant speed and approaches a lead vehicle. At the same time he drifts away from the centre of the lane. |
| **Warning signals** | Lane departure warning (S12r or S12l) is issued when the driver drifts away from the centre of the lane.<br><br>FORWARD COLLISION WARNING (S11a: caution or S11b: imminent) is issued when a forward vehicle enters within the warning zone in front. |
| **Possible integration solution** | Both warnings signal different dangers and require different actions. They should be presented simultaneously. Since both use the acoustic channel the implementation of a haptic channel should be considered. |

### A.7.3.4 Integration for three or more warning signals

The possibility of presenting three or more warning signals simultaneously can be examined by combining pairs of warning signals identified by the matrix described in A.7.3.1. If three warnings occur at the same time they represent three pairs where each pair results in one of the rules ("dm", "L", "R", "me" or "me1"). This should be demonstrated with the following example.

I) Example: simultaneous occurrence of lane departure warning, seat belt minder and forward collision warning (imminent).

II) lane departure & seat belt reminder -> seat belt minder is suppressed, lane departure shown (rule "L" or "R").

III) lane departure & forward collision warning (imminent) -> forward collision warning (imminent) and lane departure are both shown (Table A.13).

IV) seat belt minder & forward collision warning (caution) -> seat belt reminder is suppressed and forward collision warning (imminent) is shown (rule "L" or "R").

V) If the rules are applied, the result is independent of the order of application. Lane departure is shown and seatbelt warning and collision caution are suppressed.

It can be assumed that this will also work with a larger, realistic number of warnings. However, there is no proof for this assumption. A check can be done manually with a limited number of triples and the selection of these triples is done by expert judgment.

### A.7.4 System functioning conflict method to identify safety critical and time critical signals presented simultaneously (Alternative 2)

#### A.7.4.1 Procedure to identify safety critical and time critical signals that might be presented simultaneously using system function

This method is designed to identify, according to the system functioning, the situations where warning signals could be presented simultaneously. One axis in Table A.14 includes all signals that are safety critical and time critical. The other axis includes systems state parameters such as speed, road structure, etc.

The parameters listed in Table A.14 are defined by system designers and should include all parameters, which activate and deactivate each system. The goal is to identify the conditions for system function under which each signal can be displayed.

In the example, three system parameters can change the system functioning: the gear (for parking aid system), the speed (for longitudinal systems) and the type of deviation on the road (for lateral systems).

**Table A.14 — Example of system function conflict table**

| | | System functioning parameters | Gear | | Speed | | Deviation | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Values | Reverse | Drive | < 40 mph | >=40 mph | Right Deviation | Left Deviation | Any |
| | | Group 1: “Injury and damage level” and “Response immediately” signal AND mandatory | | | | | | | |
| S1 | Mandatory | SEAT BELT MINDER | X | X | X | X | X | X | X |
| S10b | - | ACC CAPACITY OVERLOAD | | X | | X | X | X | X |
| S11b | New | FORWARD COLLISION WARNING (IMMINENT) | | X | | X | X | X | X |
| | | Group 2: “Injury and damage level” and “Response within a few seconds” OR “Damage level” and “Response immediately” signals AND mandatory | | | | | | | |
| S1 | Mandatory | SEAT BELT MINDER | X | X | X | X | X | X | X |
| S7b | - | TIRE PRESSURE MONITORING (urgent) | X | X | X | X | X | X | X |
| S8r | - | BLIND SPOT DETECTION right | X | X | X | X | X | | |
| S8l | - | BLIND SPOT DETECTION left | X | X | X | X | | X | |
| S9 | - | PARKING AID ALERT | X | | X | | X | X | X |
| S11a | New | FORWARD COLLISION WARNING (CAUTION) | | X | | X | X | X | X |
| S12r | New | LANE DEPARTURE right | | X | | X | | X | |
| S12l | New | LANE DEPARTURE left | | X | | X | X | | |

The outputs of Table A.14 are several sets of signals. Each set corresponds to signals that have one common value for each parameter. If a signal has several values for one parameter, it will be included in more than one set. For each set, only one value per parameter is evaluated.

The results with the first group (“Injury and damage level” and “Response immediately” signals, and mandatory signals) provide one set:

Condition n° 1. 1
Gear=Drive, Speed>=40 mph, Deviation=RightDeviation/LeftDeviation/Any with the signals:

- S1 Mandatory SEAT BELT MINDER
- S10b Old ACC CAPACITY OVERLOAD
- S11b New FORWARD COLLISION WARNING (IMMINENT)

The other sets concern only one signal (1 Mandatory SEAT BELT MINDER):

- Gear=Reverse/Drive, Speed<40 mph and Deviation=RightDeviation/LeftDeviation/Any
- Gear=Reverse, Speed>=40 mph and Deviation=RightDeviation/LeftDeviation/Any
- The results with the second list (“Injury and Damage level” and “Response within a few seconds” or “Damage level” and “Response immediately” signals, and mandatory signals) provide three sets:

Condition n° 2. 1
Gear=Drive, Speed>=40 mph, Deviation=RightDeviation

- S1 Mandatory SEAT BELT MINDER
- S7b Old TIRE PRESSURE MONITORING (urgent)
- S8r Old BLIND SPOT DETECTION right
- S11a New FORWARD COLLISION WARNING (CAUTION)
- S12r New LANE DEPARTURE right

Condition n° 2. 2
Gear=Drive, Speed>=40 mph, Deviation=LeftDeviation

- S1 Mandatory SEAT BELT MINDER
- S7b Old TIRE PRESSURE MONITORING (urgent)
- S8l Old BLIND SPOT DETECTION LEFT
- S11a New FORWARD COLLISION WARNING (CAUTION)
- S12a New LANE DEPARTURE LEFT

Condition n° 2. 3
Gear=Drive, Speed>=40 mph, Deviation=Any

- S1 Mandatory SEAT BELT MINDER
- S7b Old TIRE PRESSURE MONITORING (urgent)
- S11a New FORWARD COLLISION WARNING (CAUTION)

The other sets concern several sets of signal without any new signals. The integration of the new systems will not impact these situations.

- Gear=Reverse, Speed<40 mph and Deviation=RightDeviation concerns the signals S1, S7b, S8r, S9
- Gear=Reverse, Speed<40 mph, Deviation=LeftDeviation concerns the signals S1, S7b, S8l, S9
- Gear=Reverse, Speed<40 mph, Deviation=Any concerns the signals S1, S7b, S9
- Gear=Reverse, Speed>=40 mph, Deviation=RightDeviation concerns the signals S1, S7b, S8r
- Gear=Reverse, Speed>=40 mph, Deviation=LeftDeviation concerns the signals S1, S7b, S8l
- Gear=Reverse, Speed>=40 mph, Deviation=Any concerns the signals S1, S7b
- Gear=Drive, Speed<40 mph, Deviation=RightDeviation concerns the signals S1, S7b, S8r
- Gear=Drive, Speed<40 mph, Deviation=LeftDeviation concerns the signals S1, S7b, S8l
- Gear=Drive, Speed<40 mph, Deviation=Any concerns the signals S1, S7b

As provided in alternative 1, for each set of signals, the need for an integration solution for comprehensibility is assessed by describing scenarios under the conditions where two signals are presented simultaneously.

#### A.7.4.2 Examples of the scenario description when signal pairs are presented simultaneously and its integration solution with Alternative 2

A scenario description in this context defines a detailed driving situation where multiple warning signals might be presented simultaneously. Each scenario description includes traffic context, road condition, vehicle dynamics, driver's manoeuvre, and possible solution for signal presentation. The description can be specified by selection among the various conditions under which warning signals are presented.

Each set of signals in Alternative 2 should be tested using a scenario description. A warning signal integration solution should be determined by the group of experts for each scenario. If several scenarios are addressed, compatibility among integration solutions should also be verified. Examples of the scenario description are shown in Tables A.15 to A.18.

**Table A.15 — Scenario 1.1 description (example based on speed range >=40mph and gear= drive)**

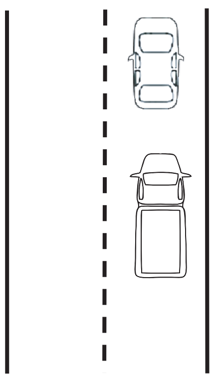
| | |
|---|---|
| **Road context**  | Road:<br>• Speed range >= 40km/h,<br>• …<br><br>Traffic description:<br>• One vehicle forward with a low speed<br>• …<br><br>Weather:<br>• Dry road<br>• … |
| **Vehicle dynamic** | High speed |
| **Driver's current manoeuvre** | The driver arrives too fast on a slow vehicle. |
| **Warning signals** | S1 SEAT BELT MINDER<br>S10b ACC CAPACITY OVERLOAD<br>S11b FORWARD COLLISION WARNING (IMMINENT) |
| **Possible integration solution** | In this situation, the human factors experts will put the warning solutions (which warnings to be presented to the driver, when, and how present them) considering the input of technical experts.<br>For this example, S1 and S10b are less important than the other one. |

**Table A.16 — Scenario 2.1 description (example based on Gear=Drive, Speed>=40 mph, Deviation=Right Deviation)**

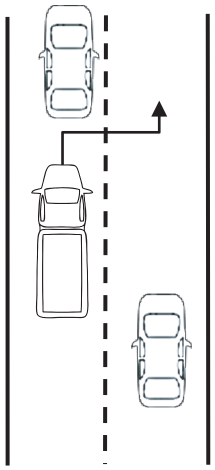
| | | |
|---|---|---|
| **Road context** |  | Road:<br>• Speed range >= 40 km/h,<br>• Road structure = two or more lanes<br>• …<br><br>Traffic description:<br>• One vehicle forward with a low speed<br>• One vehicle in the left lane with a high speed<br>• …<br><br>Weather:<br>• Dry road<br>• … |
| **Vehicle dynamic** | | High speed and low tire pressure. |
| **Driver's current manoeuvre** | | The driver has initiated an avoiding manoeuvre to return to the right lane which has triggered the blind spot warning signal and the lane departure warning. |
| **Warning signals** | | S1 SEAT BELT MINDER<br>S7b TIRE PRESSURE MONITORING (urgent)<br>S8r BLIND SPOT DETECTION RIGHT<br>S11a FORWARD COLLISION WARNING (CAUTION)<br>S12r LANE DEPARTURE right |
| **Possible integration solution** | | In this situation, the human factors experts will put the warning strategies (which warnings to be presented to the driver, when, and how present them) considering the input of technical experts.<br>For this example, S1, and S12r are less important than the other ones. |

**Table A.17 — Scenario 2.2 description (example based on Gear=Drive, Speed>=40 mph, Deviation= Left Deviation)**

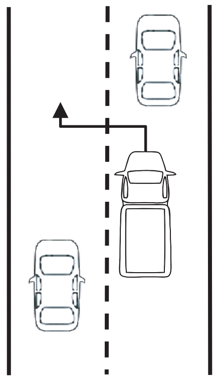
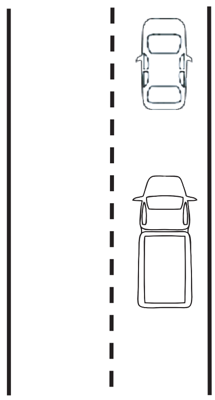
| | |
|---|---|
| **Road context**  | Road:<br>• Speed range >= 40 km/h,<br>• Road structure = two or more lanes<br>• …<br><br>Traffic description:<br>• One vehicle forward with a low speed<br>• One vehicle in the left lane with a high speed<br>• …<br><br>Weather:<br>• Dry road<br>• … |
| **Vehicle dynamic** | High speed and low tire pressure. |
| **Driver's current manoeuvre** | The driver has initiated an avoiding manoeuvre to go in the left lane which has triggered the blind spot warning signal and the lane departure warning. |
| **Warning signals** | S1 SEAT BELT MINDER<br>S7b TIRE PRESSURE MONITORING (urgent)<br>S8l BLIND SPOT DETECTION LEFT<br>S11a FORWARD COLLISION WARNING (CAUTION)<br>S12l LANE DEPARTURE left |
| **Possible integration solution** | In this situation, the human factors experts will put the warning strategies (which warnings to be presented to the driver, when, and how present them) considering the input of technical experts. For this example, S1 and S12l are less important than the other ones. |

**Table A.18 — Scenario 2.3 description (example based on speed range >=40 mph and gear= drive)**

| | |
|---|---|
| **Road context**  | Road:<br>• Speed range >= 40 km/h,<br>• …<br><br>Traffic description:<br>• One vehicle forward with a low speed<br>• …<br><br>Weather:<br>• Dry road<br>• … |
| **Vehicle dynamic** | High speed and low tire pressure. |
| **Driver's current manoeuvre** | The driver has to brake to avoid the forward vehicle but the tire pressure monitoring indicates a tire problem. |
| **Warning signals** | S1 SEAT BELT MINDER<br>S7b TIRE PRESSURE MONITORING (urgent)<br>S11a FORWARD COLLISION WARNING (CAUTION) |
| **Possible integration solution** | In this situation, the human factors experts will put the warning strategies (which warnings to be presented to the driver, when, and how present them) considering the input of technical experts.<br>For this example, S1 is less important than the other ones. |

## A.8 Verification of integration solution to reach to the best compromise

By following the procedure according to A.5 and A.7, system developers can identify warning signals that should be integrated and analysed for each of the scenarios. Verification should be carried out to confirm that the integration concept is valid. Apart from verification by inspection, an objective testing should be conducted. Appropriate testing method(s) to verify experimentally whether the designed integration works to improve the performance characteristics needs to be developed. Descriptions of methods in development are provided in Annexes B and C.

If verification shows that the integration is not appropriate for a specific scenario, the integration solution should be rechecked and additional concepts of integration should be considered. The best compromise should be chosen for integration solutions that are not verifiable for all solutions. The decision should be made by expert judgment on the limitations of integration within a certain scenario and the probability of the scenario occurring in the real-world.

# Annex B
(informative)

# Timely Comprehension Methodology

NOTE The information contained in this Annex describes a method of testing one or more warning signals/signals to determine whether drivers are able to comprehend it/them in a timely manner. Work is ongoing to validate this methodology. At this time, however, the work is not sufficiently developed so that a decision on technical merit can be made.

## B.1 Overview

### B.1.1 Background

Timely Comprehension is a laboratory methodology used to evaluate integrated warning systems in development. This methodology can help identify comprehension/distinguishability issues prior to full system development. Timely Comprehension is based on the premise that each warning signal presented in the vehicle should be comprehended and clearly distinguished from other warning signals in an integrated context. Comprehension is a dependent measure employed throughout automotive research to evaluate whether a user population can correctly perceive and interpret warning signals. While it is possible that a driver might respond appropriately without complete understanding of a warning signal, a well-integrated system should have demonstrated comprehensibility and distinguishability among warning signals. Warning signals should not be confused by drivers with other information presented.

Timely comprehension entails two dependent variables:

— Complete and accurate interpretation of signal;

— Accuracy within a specified exposure time.

Comprehension testing employs methods which have been validated through many years of surface transportation research, and measures, which are readily collected. For this methodology comprehension accuracy is assessed via the rating scale developed for SAE J2830 Comprehension Testing of In-vehicle Icons [1]. Comprehension of the presented warning signals is tested after a brief, predefined exposure time, which is referred to as Maximum Exposure Time (MET). MET is not meant to represent the length of time before a driver should begin a response following warning signal presentation. Instead, MET is defined as the maximum exposure time of a warning signal before or at which point comprehension should be demonstrated in order for a warning signal to be considered well integrated. MET is based upon previous research of Perception Response Time and is currently set at 2,5 sec.[2,3,4] Participants are instructed to verbalize the meaning of the warning signals either immediately upon recognition or once they are prompted following MET. This procedure assumes that if the participant cannot verbalize the meaning of the actual warnings (e.g. not fake warnings), then it is likely because of confusion with or masking by other signals.

In order to familiarize participants with the warning signals of interest, a tutorial, which presents and describes the meaning of all signals to be tested, is created and shown prior to participation in the first testing session.

Testing is conducted in a built-up cabin or actual vehicle in which warning signals are presented as intended in the actual vehicle. Participants are shown driving situations which represent conditions under which the warning signals of interest would be presented in the real world. The timing of the event which triggers the warning signal is varied between driving situations. Some driving situations have no event, and no warning signal is presented. A secondary task should be included to visually distract the participant.

All participant responses should be recorded and placed into one of the comprehension rating categories after being individually examined by a panel of experts. Warning signals will be considered well integrated if at least 85 % of participant responses demonstrate comprehension before or immediately following a MET of 2,5 sec.[5]

While simultaneous (or in close temporal proximity) warning signal presentation is likely very infrequent, it is still an important situation that requires evaluation, if a warning strategy/design allows such presentation. As described in this Annex, the Timely Comprehension methodology is focused on the evaluation of single warning signal interpretation in an integrated context. However, this methodology could also be applied to multiple simultaneous hazards/signals.

### B.1.2 Advantages of timely comprehension methodology

A verification method is helpful to confirm that the integration of all warning signals in the vehicle has been conducted successfully. Although it is a laboratory methodology, Timely Comprehension provides a tool to identify integration problems and is founded upon previous human factors automotive research. This methodology is not intended as a replacement to on-road, empirical research that examines responses in specific situations. Rather, it may compliment on-road or valid simulator studies, once standardized verification methods have been produced.

Timely Comprehension is a controlled, repeatable methodology that can be conducted in a laboratory without the need of a driving simulator or on-road study. It employs a repeated measures design that controls for individual differences and reduces the number of needed participants (as compared to a between-subjects design). Unlike simulator and on-road investigations of integrated warning signals, Timely Comprehension is not limited to the investigation of a single scenario per participant. This advantage results in a shorter timeline per study and reduced sample size requirements.

Further, the empirical demonstration of comprehension comprises several of the components for a correct response to a warning signal given in a real-world traffic situation, namely, perception, correct interpretation and distinction from other information, all in a timely manner. If these criteria are met, it may increase the likelihood that a participant would be in a position to take corrective action (to the degree that it is possible) in a situation warranting a warning signal. As stated in the recent driver distraction research plan put forth by NHTSA, “The human factors challenge has been to determine interface requirements that provide warning signals to distracted drivers that are acceptable, detectable, understandable, and that lead to an appropriate crash avoidance response.”[6]

The method may also identify problems that might cause an inappropriate response. Startling, freezing or incorrect interpretation of a warning signal are indications that a modification of the integrated warning system might be required.

Comprehension accuracy provides insight into the specific design attributes and interpretation of an integrated system.

NOTE Comprehension of a warning signal may range considerably with regard to specificity (e.g. “Lane departure right side of vehicle” to “Caution”). This is especially true if a master warning signal is used.

### B.1.3 Limitations of timely comprehension methodology

Not all experts currently agree that comprehension is necessary to prove effective integration. Requiring timely comprehension may be a more stringent criterion for determining an effective integration than lack of an inappropriate response.

Timely Comprehension methodology does not allow for observation of a participant’s reaction/response (in terms of vehicle control) to a warning signal.

## B.2 Individual warning system evaluation prior to timely comprehension

Safety systems in vehicles are evaluated individually to ensure they are understood by the driver and elicit the correct response in a timely manner. However, it is possible that warning systems could be designed independently from one another with minimal or no concern for other warning systems present within the vehicle. In addition, individual systems might be designed with no knowledge of the intent to combine with another independent system (e.g. in the event that an OEM buys separate systems from different suppliers). For example, a similar “beep” tone might be used both for a caution-level warning signal for forward collision and for a low fuel warning signal, thus resulting in driver confusion.

The Timely Comprehension methodology does not take the place of individual system evaluation. In fact, a prerequisite to the proposed methodology is that individual warning systems have previously been designed according to human factors principles and evaluated as individually effective prior to integration into the vehicle. However, the lack of evidence of inappropriate response to an individually-examined warning signal does not mean that there will be a lack of an inappropriate response when the warning system in question is integrated with all other in-vehicle warning systems. The focus of the Timely Comprehension methodology is solely to ensure that all warning signals are comprehended and distinguished among each other in the *integrated* setting. Essentially, Timely Comprehension is an integration comprehension methodology used to conduct an initial evaluation of the integration of all warning systems.

## B.3 Experimental setup

The experimental apparatus should contain all necessary equipment to present sensory information as intended in the design of the HMI of interest. The acoustic and lighting environments should approximate those of the actual vehicle in a driving environment as much as possible. Ideally, an automotive built-up cabin (buck) or actual vehicle should be used. A laboratory environment is suitable for this type of study.

To ensure realistic presentation of information, warning signal presentation should replicate as exactly (localization, intensity, display, etc.) as possible what will exist in the production vehicle. If warning signals are presented to the participant independent of the instrument cluster, the experimental apparatus should be adapted to present the information as intended (e.g. on a side-view mirror and rear-view mirror).

Video projection/display equipment capable of displaying scenario videos is required for this testing. Secondary task equipment (e.g. radio, navigation system, etc.) is also needed.

## B.4 Participants

The participant sample should consist of licensed drivers of both genders with representation of both younger and older drivers. Prior to the tutorial, the participants should not be familiar with, or technically knowledgeable about, the specific driver interface under investigation. The participants should be licensed in the class of vehicles being studied (automobile, truck, etc.) Other relevant characteristics of the participants should be recorded (e.g. gender, age, and driving experience). At least 20 % of the participants should be over 50 years of age.

## B.5 Scenarios

Visual scenarios for testing should be created to provide a context similar to the real-world situation in which each warning signal would be presented to a driver. Video images will be shown to participants that present the situation(s) in which a warning signal would be presented. It is critical that these video scenarios appear as realistic as possible for each situation. Videos showing non-event driving should also be created to be used during non-event/no warning signal presentation trials. Well-executed videos of driving scenarios can successfully communicate a driving scenario consisting of a chain of events in which the driver becomes immersed. The video images are projected so that participants view the scenes at a distance and size that approximates a natural driving scene.

Standardization of video scenarios would greatly enhance the degree to which results could be compared between companies/institutes and increase the likelihood that benchmarks could be set.

## B.6 Secondary tasks

A secondary task, intended to visually distract the participant, is another important component of this methodology.

In order to reduce artificial fixation during warning signal presentation, a secondary task should be administered simultaneously. Attempts should be made to ensure that participants are engaged in a task when warning signals are presented. Tasks should be long enough to effectively engage the participant during warning signal presentation while being consistent with the overall concept of improving interior design and overall usability. Possibilities include radio, HVAC, and navigation tasks. Presentation of the warning signals and timing of the hazard scenario should be varied with regard to task initiation to decrease anticipation and prediction of event by participant.

## B.7 Tutorial

In order to familiarize participants with the warning signals of interest, a tutorial is created and shown prior to participation in the testing session. This tutorial is analogous to an introduction that might be given at a dealership or an interactive owner’s manual. Such minimal introduction to the warning signals prior to testing is needed in order for drivers to be able to demonstrate comprehension of an integrated system.

The tutorial should explain (in layman's terms as much as possible) and demonstrate each individual warning signal as accurately as possible. The terminology used to describe the warning signals should match what the participant will be asked to use in their response during testing. Participants should only view the tutorial once prior to testing. Further research is needed to develop recommendations for when this tutorial should be reviewed related to testing (e.g. immediately after versus 3 to 4 days before participation).

The tutorial also should contain a method to ensure that the participant actually viewed the tutorial. A cue can be placed within the video instructing the participant to contact the experimenter.

EXAMPLE At the end of the tutorial, a screen reads, “Please email the experimenter the number of red circles that are on the screen”.

## B.8 Maximum exposure time (MET)

MET is defined as the maximum exposure time of a warning signal before or at which point comprehension should be demonstrated in order for a warning signal to be considered to have been quickly and correctly interpreted. MET is analogous to the occlusion method shutter open time and is based upon perception-response time (PRT), which refers to the time required to perceive, interpret, decide, and initiate a response to a stimulus. PRT does not include physical reaction time. The proposed value is currently 2,5 s and is supported by human factors research into PRT.[2,3,4]

NOTE MET does not represent the length of time before a driver should begin a response following warning signal presentation.

## B.9 Warning signal grouping

The Timely Comprehension methodology allows for a relatively large number of warning signals to be examined against one another. It is feasible that 15 to 20 different warning signals could be examined for effective integration within a single session. However, as more warning systems are added to the vehicle, the total number of warning signals that could be presented to the driver will increase over the maximum number of warning signals that could be tested within a single session.

Therefore it becomes necessary that warning signals be separated in some way into smaller groupings that can be tested.

It is recommended to test as many warning signals as possible against one another in a single session.

## B.10 Experimental design

A repeated measures design is proposed so that participants' perception and comprehension are tested for warning signals of interest. It is critical to ensure that an effective integration has been achieved (that warning signals are not confused with one another, and that intended urgency differentiation is conveyed).

As previously mentioned, prior to the testing session, participants should be shown a video tutorial detailing the warning signals of interest.

The session tests the comprehension of integrated warning signals individually in order to ensure that compatible and effective warning signal integration has been achieved (e.g. warning signals are not confused with one another). Warning signal presentation should be counterbalanced across participants. If timely comprehension is not demonstrated for all single sources of information, warning signal redesign should be considered.

Participants are presented a driving context and given cognitive-loading secondary tasks.

Event trials (i.e. trials in which warning signals of interest are presented) are to be intermixed with non-event trials in an effort to reduce participant expectancy.

## B.11 Test procedure

### B.11.1 Tutorial

Participants should be exposed to the pre-testing tutorial approximately 3 to 4 days before the first testing session.

### B.11.2 Introduction

Participants should be greeted in a consistent manner. Additionally, all participants should be told by the experimenter, prior to testing, that the experiment is not intended to test their competence or abilities, but rather is intended to assess the design of the systems being tested. Although there are no physical or mental risks involved in this type of study, all participants should be informed that they may stop their participation at any time for any reason.

Participants should be informed that they will be participating in a study that is investigating the interior design and usability of a vehicle. They should then be introduced to the secondary task and experimental apparatus. The experimenter should then explain that performance in completing the secondary task is important. Although usability of the secondary task system is not under investigation, it is important to instruct the participant that this is equally important to demonstrating warning signal comprehension. The experimenter(s) should then ask whether all warning signals from the tutorial video were completely understood by the test participant and offer to answer any questions the participant has regarding the warning signals.

Participants should be instructed to begin secondary tasks immediately after receiving instructions. If a warning signal is presented, participants should be instructed to verbalize the meaning of the warning signal. The meaning of the warning signal can be verbalized immediately upon recognition, or the participant can wait until they are prompted by the word “time”, following MET. Participants are instructed to say “I don’t know” if they do not know the meaning of a presented warning signal. It should be emphasised that “I don’t know” is an appropriate response and better than guessing, if they have little confidence that they are correct. When “time” is called, the participant should respond by verbalizing either the meaning of the warning signal or the phrase “I don’t know.” Participants are also instructed to stop secondary task performance while giving the response.

A complete and succinct answer is needed for timely comprehension to be achieved. Participants should also be instructed not to pause while answering, nor to give a partial description of the meaning of the warning signal. Doing so will constitute a miss.

At the conclusion of MET, the stimuli for a specific warning signal shall end. This ensures that the participants will not continue to be exposed to information after MET has passed. Additionally the video scenario should be shut off at this time.

### B.11.3 Procedural summary

In order to minimize expectancy, videos/scenarios containing no hazard, warning signal, or required response should be interspersed in the session. However, a secondary task should be administered during each scenario. Breaks for the participant should be planned to reduce expectancy and maintain a state of participant readiness.

NOTE Procedural example:

- Driving context video displaying a specific driving situation is started.
- Participant is given secondary task instructions, told to begin secondary task.
- Note: Participant has previously successfully completed trial scenario and has been instructed to occasionally monitor driving scene, which will be representative of the conditions under which a warning signal would be given in the real world (if one is given).
- For hazard/alert scenarios, driving context video reaches trigger point for warning signal presentation.
- Warning signal is presented for maximum-exposure time (MET) and then participants are prompted (with “time”) to immediately verbalize the meaning of the warning signal (if they have not already done so).
- As MET is reached, and “time” is called, all sensory cues for the specific warning signal are removed and video is stopped to ensure participants are not exposed to information following MET.
- Participant response is video-recorded for subsequent comprehension analysis. Note: Participants are not told whether they correctly demonstrated comprehension.
- After participant response, the video is restarted and secondary task resumed until the end of task completion or driving scene.
- The next driving context video is displayed and the process repeats. Note: warning signals should be counterbalanced as much as possible across participants.

### B.11.4 Post-test questionnaire

Following the testing phase, subjective ratings on each individual warning signal should be collected. These ratings should focus on whether the participant thought the warning signal was effective (i.e. would result in a proper response). A possible post-test question: “Which (if any) of these warning signals were hard to comprehend and why?” Effort should be taken to try to understand why a participant did not comprehend a warning signal that received an “I don’t know” response.

## B.12 Data collection, measures, metrics

Maximum exposure time: Comprehension should be demonstrated before or immediately following MET (within 1 second).

Comprehension accuracy: Comprehension accuracy should be assessed via a rating scale developed for SAE icon comprehension testing (see Table B.1) [1]. Comprehension ranking greater than 2 indicates redesign should be considered.

**Table B.1 — Comprehension testing rating scale**

| Comprehension rating scale | Description of rating |
|---|---|
| 1 | Response matches the intended meaning of the icon exactly. |
| 2 | Response captures all major informational elements of the intended meaning of the icon, but is missing one or more minor informational elements. |
| 3 | Response captures some of the intended meaning of the icon, but it is missing one or more major informational elements. |
| 4 | Response does not match the intended meaning of the icon, but it captures some major or minor informational elements. |
| 5 | Response does not match the intended meaning of the icon, but it is somewhat relevant. |
| 6 | Response is in no way relevant to the intended meaning of the icon. |
| 7 | Participant indicated he or she did not understand the icon / "I don't know". |
| 8 | No answer. |
| 9 | For safety critical icons only, the response indicates that the participant perceived the message to convey the opposite action as that intended by the icon. |

After the testing session, a checklist of key elements for each particular warning signal should be used to identify the overall comprehension rating for each warning signal presentation. Ratings of 1 or 2 indicate high comprehension. Ratings of 3 or 4 indicate low comprehension. Ratings between 5 and 8 indicate no comprehension. A rating of 9 represents critical confusion.

Warning signals should be considered effective if 85 % of participant responses demonstrate comprehension before or immediately following MET. The 85$^{th}$ percentile represents a common design standard in traffic engineering as well as the percentile used in the SAE Icon Comprehension Testing methodology.[1,5] A panel of experts should examine all responses in order to place responses into one of the comprehension categories. In cases of varying opinions, a consensus opinion should be followed.

Table B.2 details an example testing session.

**Table B.2 — Testing phase example**

| warning signal # | Warning signal name | Key response elements | Comprehension rating demonstrated |
|---|---|---|---|
| 1 | Lane departure (LD) right | Vehicle is departing from the lane to the right side. | 1 |
| 2 | Cell phone | Incoming cell phone calls. | 1 |
| 3 | Lane departure (LD) left | Vehicle is departing from the lane to the right side. | 3 |
| 4 | Curve speed | Vehicle is approaching a curve too fast. | 7 |

In Table B.2, the participant failed to comprehend the curve speed warning in warning signal #4 and was missing a major informational element in warning signal #3.

## B.13 References

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# Annex C
(informative)

# Appropriate Response Methodology

NOTE The information contained in this Annex describes a method of testing multiple simultaneous warning signals to determine whether drivers are able to respond to it/them in a timely manner. Work is ongoing to validate this procedure. At this time, however, the work is not sufficiently developed so that a decision on technical merit can be made.

## C.1 Advantages and limitations of the Method

### C.1.1 Advantages

The primary advantage of this methodology is that the evaluator is able to observe how participants respond to the warning signals in a given scenario. Additional advantages are:

— This method can be used to objectively measure performance metrics related to warning responses.

— This method does not require any additional equipment that OEMs currently do not have.

## C.2 Limitations

Limitations include:

— It cannot be used to evaluate effectiveness of the integration of multiple warning signals that are not presented simultaneously (or in close temporal proximity).

— It requires a high-fidelity driving simulator or instrumented vehicle, and may be otherwise resource-intensive (e.g. as a between-subjects evaluation, the number of participants required for statistical analysis may be quite high).

— It can be difficult to develop scenarios that can be generalized to many different scenarios.

— Another difficulty is to control timing to generate the exact same situation where two or more warning signals are presented because the subject vehicle is under control of a participant. If the situation is not the same, behavioural response may not the same.

— This method is inefficient to collect enough amounts of data since repeated data is not available from each subject because a hazardous situation should not be predicted by a participant to observe evasive behaviour.

## C.3 Background

This method is intentionally vague and is meant to provide guidance to those who will be evaluating warning systems. There are many aspects of this method that will be directly dependent on what systems are under investigation. This methodology is to be applied to the evaluation of multiple hazard scenarios involving the advent of multiple, simultaneous warning signals. It is not suitable for the evaluation of distinguishability and comprehension among integrated in-vehicle warning signals that are not presented simultaneously.

### C.3.1 Why should responses to multiple simultaneous warning signals be tested

— Drivers may be startled by multiple warning signals issued simultaneously and perform a detrimental manoeuvre.

— Drivers may be overloaded by multiple warning signals issued simultaneously, “freeze up” and not respond at all to the warning signals or the response may be delayed.

— Drivers may be confused or misinterpret multiple warning signals issued simultaneously and not respond to all of the warning signals.

### C.3.2 When should responses to multiple simultaneous warning signals be tested

— A new high-urgency warning signal is added to a vehicle with existing high-urgency warning signals that could occur simultaneously under certain multiple hazard scenarios.

— A new high-urgency warning signal is being integrated with another imminent warning signal designed to elicit a similar response.

— There are multiple high-urgency warning signals which could be confused with one another when presented simultaneously, because they share common characteristics such as:

  — Modality (e.g. two audible signals).

  — Presentation pattern (e.g. audible tone and haptic warning signal).

## C.4 Experimental setup/apparatus

### C.4.1 Experimental apparatus

This experiment can be conducted in a simulator; in an instrumented vehicle on a test track, on a public or private roadway under controlled conditions.

NOTE When on-road testing is used, this can be accomplished using foam vehicles, other barriers, etc. to ensure the participant is not harmed.

### C.4.2 Participants

#### C.4.2.1 Background

Participants in the study should be selected to provide a representative cross section of the general driving population. The participants should be licensed drivers, in the class of vehicles being studied (automobile, truck, etc.), and they should not be familiar with, or technically knowledgeable about, the specific HMI under investigation. Other relevant characteristics of the participants should be recorded (e.g. gender, age and driving experience). At least 20 % of the participants should be over 50 years of age.

#### C.4.2.2 A ruse should be used to avoid biasing the participants' responses to the warning signals

The participants should have no preconceived notions regarding the warning signals when starting the evaluation. Therefore, participants should be informed that they are going to evaluate a feature(s) not associated with the warning signals that are actually under investigation. This “ruse” evaluation should be designed around some type of secondary task that serves to visually distract the participant.

#### C.4.2.3 Participants should be introduced to the warning signals and their purposes

The participants should have the warning signals introduced and explained to them prior to the beginning of the evaluation. This can be accomplished by instructing the participants that there is another system, on which their opinions are being solicited, and then introducing and explaining the different warning signals to them. Additional warning signals to the ones under review should be introduced, and the participants' subjective opinion of these warning signals should be collected to ensure that the warning signals were truly understood, and to keep the participant immersed in the ruse.

### C.4.3 Scenarios

If a simulator is used, the equipment should be of sufficient quality and sophistication to produce a driving scenario that will compel the participant to treat the study as if he or she were driving on a public road (i.e. attempting to stay on the road, avoid collisions and maintaining a reasonable speed). This level of fidelity can be obtained through the use of instrumented vehicles operated on public or private roads under controlled conditions, or through the use of a research-grade driving simulator, (moving- or fixed-base and multi- or single-channel).

Real-world scenarios should be developed that demonstrate when, where, and how incidents will occur where multiple warning signals would be displayed simultaneously or in close temporal proximity. If there are multiple warning signals that will occur under different driving conditions (e.g. leaving a lane, in a curve, etc.), scenarios that address these conditions simultaneously should be developed and evaluated. Scenarios need to be developed that can be generalized to as many different conditions as possible. Once a group of warning signals has been tested and approved, the same scenario may be able to be modified by adding a new active safety hazard and associated warning signal to evaluate whether or not the new warning signal will be in conflict with other warning signals.

### C.4.4 Secondary tasks

There should be a visual distraction event that directs the driver’s attention away from the road scene when the multiple warning scenario is presented. This should be directly related to the “ruse” system under evaluation. For example, the radio task could include changing to various radio frequencies, inserting CDs, selecting specific tracks on the CD, etc. This distraction event should be part of the “ruse” evaluation to increase the efficiency of the evaluation. The warning signals should be presented when the participant is fully engaged in the secondary task as a distraction event. The warning signals should also be evaluated without any secondary task to provide a baseline.

## C.5 Experimental design

Participants who are aware that their response to a particular warning scenario will be tested will not respond as they would under real world conditions where they would not have such an expectation. Because it is important to elicit an unbiased response from test participants, each participant would be tested in only one surprise scenario; otherwise they might form expectations about their experience. The baseline condition is also a surprise scenario which can only occur one time per participant. A between-subjects design usually implies that a larger number of participants are needed to test multiple scenarios; however, in this case, because the response is to only one warning event (involving multiple warning signals) is collected, the time per participant will be relatively short.

## C.6 Example test procedure

Participants are first introduced to the test vehicle or testing apparatus and instructed to drive until they are comfortable with it (at least for 5 min).

Participants are then introduced to the “ruse” evaluation, and the “ruse” evaluation begins. The “ruse” system is introduced and the participant is instructed as to how the evaluation will occur. The participants are then informed that there are warning signals on which their opinion would be useful. The warning signals that will be evaluated as well as other warning signals not under evaluation are introduced. The participants are then asked to provide their subjective opinion on each of the warning signals.

The participants are then given instructions to begin the “ruse” evaluation. The participants should be engaged in this evaluation for a brief period of time, but long enough to become immersed in the driving scenario.

The secondary task should be presented slightly before the warnings are presented to ensure that the participant is engaged in the task during the surprise scenario.

## C.7 Data collection, measures, metrics

The participants' response(s) to the warning(s) are the primary metric(s) for this evaluation. The following is a partial list of metrics related to the participants' responses that could be collected and evaluated:

- Did the participant respond in a manner that would avoid a conflict or reduce the severity involved?
- Did the participant respond immediately to the warning signals? Was the response delayed because he or she was “frozen”?
- Was the response the result of an intended action?
- Did the response occur as a result of an intended action or was it accidental?
- Response time, how fast was the response?
- How does the response time to this warning signal compare with response time to other warning signals (individual or integrated)?
- Eye glance behaviour, how fast did the warning signals redirect the participants visual attention?
- Did the participant respond prior to looking at the road scene?

## C.8 Conclusion

The experimenters will need to collect and analyse the metrics that they find to be most appropriate for their evaluation. This methodology is intentionally vague and meant as a starting point to provide guidance to those who will be evaluating warning systems.

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