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Road vehicles — Ergonomic aspects of in-vehicle presentation for transport information and control systems — Warning systems

Véhicules routiers — Aspects ergonomiques de la présentation des systèmes de commande et d'information des transports à l'intérieur des véhicules — Systèmes avertisseurs

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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ISO/TR 16352 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 13, *Ergonomics applicable to road vehicles*.

Introduction

From a task/function analytic perspective, the task of driving is composed of three major interlinked categories of activity (Hancock and Parasuraman, 1992):

a) vehicle control;

b) navigation;

c) collision avoidance.

Each of these functions contribute to the overall workload imposed on the driver. Even under routine, low-traffic conditions, the driver must co-ordinate several tasks together and, generally, can do so quite efficiently. Many of these task components become highly automatized with practice, so that under normal driving conditions the demands of divided attention on the drivers will generally be within the limits of their attentional capacity. However, during more demanding traffic situations, for example, when traffic density increases or at intersections or traffic roundabouts, divided attention demands may sometimes exceed a driver's capabilities.

The driver has to deal with a lot of information which has different situation-dependent priorities and which is more or less expected by the driver. Highly demanding situations are characterized by high time and spatial density or by an extended spatial range of information. Parts of the information are natural and parts are coded within or outside the vehicle. While receiving, processing and reacting to the information, the driver can be overtaxed, which results in critical driving situations with increased accident probability.

This is the motivation to support the driver with assistance systems. The degree of assistance available seems likely to increase considerably over the coming years. Assistance systems can, for example, control speed and distance between vehicles and vehicle position in relation to the road. They not only aim to optimize driver strain and increase driving safety, but also to achieve maximum driver acceptance. For example, the S.A.N.T.O.S system is a (adaptive) driver-assistance system which integrates systems like active cruise control (ACC), heading control (HC), navigation, telephone and radio (Weiße *et al.*, 2002).

Most of these assistance systems announce any abnormal or dangerous state of the car or the driving environment to the driver and require a relatively quick reaction by the driver. These systems warn the driver and convey an appropriate message to the driver. So, with an increasing number of assistance systems, more respective warnings are expected. These warnings need to be designed individually and with respect to their interrelation.

Road vehicles — Ergonomic aspects of in-vehicle presentation for transport information and control systems — Warning systems

1 Scope

This Technical Report provides a literature survey about the human-machine interface of warning systems in vehicles, including studies of ISO/TC 22/SC 13/WG 8 and ISO/TC 204/WG 14. It covers the experimental experiences about the efficiency and acceptance of different modalities and combinations of warnings, and the design of the sensorial, code and organizational parameters of visual, auditory and tactile warnings (as well as concluding recommendations). The survey should initialize standardizing activities of ISO working groups, e.g. ISO/TC 22/SC 13/WG 8.

This literature survey comprises the human-machine interface issues of warning systems in automobiles. The discussion of warning signals in general is dealt with in Clause 2 and concerns the definition of warning signals, their failure and urgency aspects. Alarm theories are briefly dealt with here. The basic psychological and physiological aspects of warnings in vehicles are the subject of Clause 3. Some issues of human behaviour, which are relevant to handling warnings, are described.

Due to their importance, the sensorial modalities are introduced separately in Clause 4. Auditory and tactile presentations are becoming more and more important, which is reflected in the structure of the next three Clauses 5, 6 and 7. The specific psychological and physiological bases, benefits and types of displays for each sensory modality are presented in these clauses. Clause 5 is dedicated to visual warning displays with a few examples of the sensorial-related parameters. Symbols, icons and text are discussed extensively. Other coding and organizational features are handled as far as warning signals are affected (colour, blinking, structures, etc.).

Clause 6 is dedicated to auditory warning displays. The basic differences and the respective benefits of tonal signals, auditory icons and speech output are explained. This is the largest clause because of its significance for oncoming information and warning systems in cars. The display parameters, which are particularly relevant for auditory warning signals, are presented in more detail, i.e. startling effect, temporal and spatial characteristics. The new auditory icons are elaborated more in detail because of their relevance for collision warning systems. The sensorial, coding and organizational parameters of speech output are described in a comprehensive manner.

Clause 7 is dedicated to tactile warning displays. Although the potential of tactile warnings has been clearly demonstrated, data for their design is very scarce.

The redundant presentation of warnings is described in Clause 8. The experimental results of different visual/auditory combinations are presented, as well as visual/auditory/tactile combinations. The possible transfer of master alertings from the avionic environment into the automobile environment is discussed. Other concepts like the graded sequence of warnings are included.

The experimental results with different warning signals and their combinations are presented in Clause 9 with respect to type, code and modality of the warnings. The benefits of visual, auditory and tactile warnings depend on whether objects, spatial relations or abstract information are transmitted verbally or non-verbally. A series of field experiments with symbolic, written, tonal, spoken and tactile warnings are reported.

Clause 10 includes some of the assistance systems that have just been introduced, such as distance warning systems, or that are about to be introduced, such as side-obstacle warning systems. All of these are relatively time-critical and need carefully designed warnings with a particular emphasis on auditory and tactile displays. The recent experimental results are cited.

In Clause 11, warning systems in other domains, especially avionics, are described. The extensive experiences with the problems of several time-critical alarms in aircrafts as well as the flood of alarms in power plants will be exemplified.

Clause 12 is dedicated to the discussion of the previous clauses and their relevance for warnings in vehicles.

Drivers are assisted in highly demanding driving situations by technical systems. There will be more assistance systems in the near future with appropriate warnings for the driver. Not all warnings will be a priori appropriate. Guidance from this study will help ensure they are "appropriate". The scope of this Technical Report is to survey the literature about the human-machine interface of warning systems. It includes papers about the efficiency and acceptance of different modalities and combinations of warnings and the design of the sensorial, coding and organizational parameters of visual, auditory and tactile warnings.

2 Warning signals

2.1 Criteria of warning effects

The word "warning" implies a range of levels from simple situation indications to more imperative warnings and commands directed toward the driver to perform a certain task (ISO/TC 204/WG 14, Komoda and Goudy, 1995).

There are several technical processing stages of warnings (Kopf, 1998):

— detection of object, reading of sensor data, filtering;

— recognition of situation;

— evaluation of situation;

— output of warning.

Warnings are designed to provide someone, exposed to that product or situation, with information in addition to that which that person could reasonably be expected to possess. The designer is trying in some way to influence the behaviour of the recipient of the warning. This could mean preventing someone from doing something that he or she otherwise might have done, or it could mean getting him or her to do something that might otherwise have been omitted. The receiver of the warning then has the task of deciding whether the advantages in complying with the warning outweigh the costs of doing so.

An emergency signal paradigm is usually one where two components are operating in tandem. The first component consists of a mechanical device that uses sensor logic to determine if and when to trigger a signal (Getty *et al.*, 1995). It involves proper setting of the sensor decision threshold. If the criterion is set too strictly, false signals will be minimized, but there is the possibility that dangerous situations will go unsignalled. If the criterion is set too leniently, fewer dangerous situations will go unsignalled (missed signals), but the false signal rate will rise. The solution to this dilemma requires designing the physical components of the system to optimize the trade-off between minimized false signals and maximized sensitivity.

The second component of an emergency signal response paradigm is the human operator, who is responsible for detecting, evaluating and responding (or not responding) to the signal that is generated by the sensor-based signalling system. Consideration of the second component is necessarily a more complex process than manipulating the first component, due to the cognitive and perceptual processes of the human operator.

One has to differentiate between behaviour that occurs naturally in the relevant situation without a warning necessarily being present, and the 'added value' that the warning might bring. The particular effect the warning will have has to be known, so that the relative effects of different warning variables on compliance can be assessed. The distinction between amount of compliance with and without the warning is crucial.

Warnings are artefacts. They are representations of the situations to which they refer. Most warnings serve two functions: the alerting function and the informing function. The alerting function is somewhat abstract, being emotive or motivational or both. The informing function is more explicit. For example, an auditory warning may be overwhelmingly alerting, but contain no information at all beyond the fact that something has gone wrong. Vice versa, a warning text may contain a minimal alerting effect, but may contain lots of information.

Also relevant is the knowledge of the situation in which the warning occurs. Together the factors that have an alerting function can be seen as the iconic aspects of warning. Such aspects act almost instantaneously and require little conscious information processing. Generally one of the aims of a warning is to produce a rapid alerting response which is appropriate to the product or situation. The alerting function results from more than just, for example, the signal word, but results from the entire warning-in-context.

A warning is rated information (Kopf, 1998). A good warning should include:

— an element which attracts the attention;

— a reason for the warning;

— the consequences if the warning is not observed;

— instruction for actions.

There are different false warnings (Kopf, 1998, see 2.2):

— time-dependent false warning: too early, too late;

— logical false warning: no warning in critical situation and vice versa;

— qualitative false warning: too many, too few, too strong, too weak.

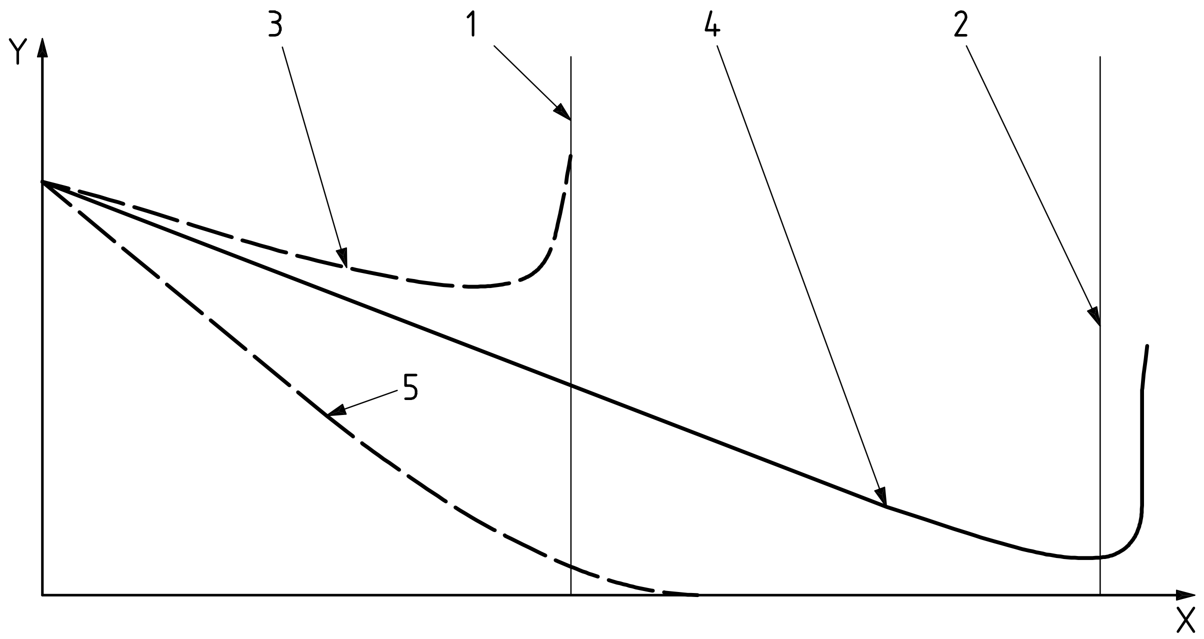
Figure 1 shows the remaining time as a function of time when the warning is successful, not necessary or too late, which results in an accident, depending on the moment of the driver's reaction.

To test the efficiency and impairment of warning systems, the following aspects have to be considered (Breuer *et al.*, 1994):

— impairment (e.g. startling effect);

— reliable detection and identification (conspicuousness, clearness);

— transformation in safe behaviour.



Key

X time

Y remaining time

1 time of warning

2 driver's reaction

3 unnecessary warning

4 successful warning

5 accident

Figure 1 — Time aspects of warning (Kopf, 1998)

2.2 Categorization of warning signal failure

Pritchett (1997) investigated the pilot's non-conformance to alerting systems (see 11.1). Pilot´s non-conformance changes the final behaviour of the system and therefore may reduce actual performance from that anticipated.

The pilots' perceived need to confirm the alerting system's commands may involve several factors, including the following.

— The pilot may be concerned that the alerting system will fail to act as it should.

— The pilot may feel the alerting system cannot consider relevant information or has different objectives.

— The pilot may place greater confidence in his own decisions than in the decisions of the alerting system.

This pilot´s non-conformance can be associated with the following reasons for warning signal failures.

— **False signals**: In theory, most design and training for emergency signals is based on the assumption that, when presented, the signal is authentic and thus heeded. However, false signals may result as the product of an over-sensitive sensor system (conservative decision criteria) (Getty *et al.*, 1995). In many cases, a given signal may be correctly generated based on a threshold violation, but may be invalid or insignificant given the specifics of the operational situation. Such inappropriate signals may create a nuisance that diverts operator attention. Elimination of all false signals is ideal, but attempts to achieve that goal by altering sensor detection decision criteria can lead to overly strict detection systems that fail to signal true emergencies. Instead, it is the responsibility of the human being to make the appropriate response decision.

When the alerting system is designed to prevent catastrophic events in the avionics, variance in the sensor measurements and unpredictability in the system dynamics requires its reasoning to be conservative (Pritchett, 1997). While a conservative design helps ensure prompt, adequate reactions to dangerous situations, it also increases the frequency of false alarms and excessive commands from the alerting system. Although the alerting system is performing to specifications, false alarms may appear to the pilot as failures of the system.

— **Missing signals**: Failures of signalling systems may take another form. Instead of generating spurious signals, they may fail to inform about legitimate danger. In many of these cases, the problem may be related to the first component of the signalling system: the mechanical sensor (Usher 1994). If the sensor's decision criterion (tolerance level) is set too strictly, then the sensor may fail to signal developing crises, or it may wait too long before warning the operator. The deactivation of a signalling system (and accompanying missed signals) are often the result of operator mistrust, caused by frequent false alarms.

  The direct effects of these failures in the avionics can lead to very high costs; for example, in the case of a collision-avoidance system, this type of failure can have catastrophic results (Pritchett, 1997). First, if the pilots are not confident that the alerting system will generate an alert when required, they may feel compelled to assess the situation regularly independent of the alerting system. Second, if the pilots feel the commanded resolution to the hazard is insufficient, they may feel compelled to make their own decisions about a resolution to the hazard, or they may execute a more severe version of the commanded resolution.

— **Multiple signals**: A third problem associated with signalling systems is the generation of multiple signals that require prioritization, or worse, that contradict each other (Bliss and Gilson, 1998). Arrays of multiple alarms can be problematic, because operators are typically not trained to prioritize them in any given manner. This problem can be addressed by utilising an urgency mapping technique (Hellier *et al.*, 1993). This technique involves manipulating aspects of an alarm stimulus to increase the perceived urgency of the signal.

— **Different situation perception**: The pilots' desire to confirm alerting system commands is a perception that, while the alerting system is functioning to its specifications, these specifications do not include all relevant information or have the same objectives as the pilots. For example, pilots indicated in a survey that they sometimes do not follow Traffic Collision-Avoidance System (TCAS) commands — or turn them off — in conditions where they have visual contact with the other aircraft or have knowledge of the other aircraft's intentions through Air Traffic Communication (ATC) (Pritchett, 1997). When pilots have a high confidence in their own reasoning and a low confidence in the alerting system's reasoning, they are more likely to act upon their own reasoning and to confirm automatic commands.

So, one of the most likely reasons why users do not comply is that the perceived benefits are not outweighed by the perceived costs of compliance. Warnings are usually used where there are risks, and in such situations there will be both benefits and costs involved in complying with the warning. The situation in which the warning occurs will be assessed using

— previous knowledge,

— natural cues from the situation or product, and

— information from the warning.

It could also be influenced by the personality or mood of the recipient.

Information should be provided to the driver whenever a warning situation occurs. The driver should not have to directly request information from the system, i.e. query the system (NHTSA, 1996).

The effects of warning signal failure may take many forms. False, missing and conflicting signals may undermine confidence in system accuracy and reduce subsequent reliance and adherence. Different situation perception by the driver can result in disregarding the warning signal. So, prior to designing the warning output in a sophisticated manner, the mechanical warning device has to be designed elaborately. Well chosen warning criteria are possibly more important than the ultimate choice of specific details of the warning signal.

2.3 Urgency mapping

ANSI standards have made the following signal words standard for communicating hazard intensities (Laux and Mayer, 1993; see 6.3.5.2):

— **DANGER**: immediate hazard which will result in severe injury or death;

— **WARNING**: hazard or unsafe practice which could result in severe injury or property damage;

— **CAUTION**: hazard or unsafe practice which could result in minor injury or property damage.

This can be used as a general classification of signals in the car, which try to attract the driver's attention to any hazardous state inside or outside the car. The communication function of a danger, warning, or caution signal (subsumed here as “warning signals”) is to alert users to the presence of a latent hazard, to let them know how hazardous it is, and to tell them what to do to avoid the hazard and what will happen if they do not act appropriately. The statement of the hazard can be in speech, text format or in pictorial/symbolic form.

In the meanwhile, the alert signal has also been defined and classified in other standards. Table 1 shows the definition and classification in MIL (Military) standard, and Table 2 and Table 3 show the one in ISO/TC 159. The definition and classification are based on the criticality, urgency of the situation and the action to be taken.

Table 1 — Examples of definitions of alert signals in Military Standard (Aircrew Station Alerting Systems)

Source	Definitions of Alert signals		
MIL-STD-411E (1 March 1991)	**Audio warning:** — Indicates the existence of a particular hazardous condition, requiring immediate corrective action	**Audio caution:** — Indicates the existence of a particular impending dangerous condition, requiring attention, but not necessarily immediate action	
	Warning visual signal: — Indicates the existence of a hazardous condition, requiring immediate action to prevent loss of life, equipment damage, or abortion of the mission	**Caution visual signal:** — Indicates the existence of a condition, requiring immediate attention but not immediate action	**Advisory visual signal:** — Indicates a safe or normal configuration, condition of performance, or operation of essential equipment or attracts attention and imparts information for routine action purpose

Table 2 — Examples of definitions of alert signal in ISO/TC159 (Ergonomics) (1)

Source	Message categories				
ISO 11429: 1996, *Ergonomics — System of auditory and visual danger and information signals*	**Danger**	**Caution**	**Command**	**Announcement/ information**	**All clear**
	Urgent action for rescue or protection	Act when necessary	Need for mandatory action	Public instruction	Danger past

Table 3 — Examples of definition of alert signal in ISO/TC159 (Ergonomics) (2)

Source	Message categories		
ISO 11428:1996, *Ergonomics — Visual danger signals —General requirements, design and testing*	**Visual danger signal**	**Visual warning signal**	**Visual emergency signal**
	Visual signal indicating imminent onset or actual occurrence of a dangerous situation, involving risk of personal injury or equipment disaster, and requiring some human response to eliminate or control the danger or requiring other immediate action	Visual signal indicating the imminent onset of a dangerous situation requiring appropriate measure for the elimination or control of the danger	Visual signal indicating the beginning or the actual occurrence of a dangerous situation requiring immediate action

For warning signals, it is often difficult to differentiate between the iconic and the informational components (see 2.1). In the case of auditory verbal warnings, this differentiation is usually clearer in that the sound has an alerting function and also precise meaning, which may be known to the recipient. The urgency, as one particular iconic feature of auditory warnings, should relate in some systematic way to the hazardousness or risk of the referent. Warnings can be said to be appropriately mapped when the rank ordering of the urgencies of the warnings is positively correlated with the rank order of the urgencies or importance of their associated referents. Then, the recipients of the warning would know how quickly they should attend to the problem signalled.

Studies with speech output have shown, that speeding up a stimulus makes it more urgent, as does raising its pitch or making it louder (Momtahan, 1990, see 6.4.4.2). Warnings can be created which can be reliably differentiated from one another in terms of their urgency.

Urgency mapping is also achievable with the iconic parts of a visual warning. For example, some colours have stronger effects on our assessment of the likely level of risk and hazard involved (see 5.3.2.3).

In the following Figure 2, there are two aspects which require mapping. The first is the relation between the iconic aspects of the warning and its perceived urgency. This is primarily a function of properties of the warning itself. The second is the relationship between the objective risk and the subjective perception of that risk. This will be affected both by prior knowledge of the procedure or situation and also by the informational properties of the warning.

For crash-avoidance warnings Lerner *et al.* (1996) recommend that multiple imminent warnings should be automatically prioritized in terms of severity and urgency (see 10.2). All warnings should be presented simultaneously by means of a visual display. Only the highest priority warning in effect should be presented by means of an acoustic or tactile display. A clearly distinguishable cue should be provided to the driver between the termination of the highest priority imminent warning and initiation of the next highest priority warning. In the case of directional warnings, the directional nature of the warning indication is sufficient to provide this cue.

The cited papers show the necessity of designing multiple warning systems with some sort of urgency mapping. The iconic cues of visual and auditory warnings have to represent the level of hazard with respect to other warnings presented at the same time. The sensorial modality has to be carefully chosen to represent the urgency correctly.

Application of the management procedure, based on the prioritization of information contents and assignment of suitable physical properties for information display, could improve the acquisition of presented information especially if multiple information were given from ITS subsystems. For example, Uno *et al.* (2001) examined the effects of information management in the situation when warning, route guidance and multimedia information were simultaneously supplied. The results revealed that the management procedure assured successful avoidance of a potentially dangerous event (rush out vehicle at blind intersection), though fewer drivers could avoid collisions when the warning was presented without an applied management procedure.

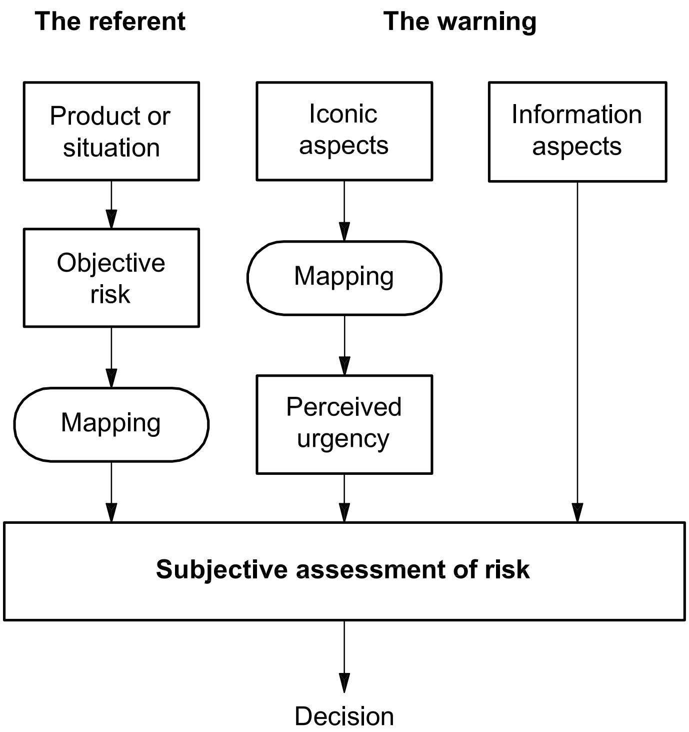


Figure 2 — Components of warning compliance

2.4 Alarm theories

There are different alarm theories which help to understand the reaction of users to warnings.

- **Classical Signal Detection Theory, SDT**: The Classical Signal Detection Theory (Green and Swets, 1966) has been utilized to examine the response to an alarm system. The theory states that detection of a signal is dependent upon two general factors. The first factor (d') is a consideration of the physical ability of the human being to detect a signal that is embedded in noise. The second factor (ß) takes into consideration person-specific qualities, such as motivation and past experience with the signal detection paradigm, that may affect the propensity of the human being to detect the signal.

  In a signal detection paradigm, the above factors, d‘ and ß, work in tandem so that one of four possible events may occur: a signal may be presented and detected (a hit); a signal may be presented, but not detected (a miss); the detector may respond even though no signal is present (false alarm); and the detector may refrain from responding when no signal is present (correct rejection). To determine detector performance efficacy, receiver-operating characteristics (ROCs) can be computed. This metric analyses hit rate (rate of correct detection) versus false alarm rate (rate of incorrect detection) for different criterion levels (typically altered by varying pay-offs).

  Although Signal Detection Theory provides an explanation of elements that influence detection of a signal, it does not adequately account for the cognitive ones.

— **Subjective Expected Utility model, SEU**: The Subjective Expected Utility model (Edwards, 1954) proposes a relatively simple mathematical model of decision making in which people assess the expected utility of an act choosing the action with the highest utility[1)]. The subjective expected utility of an action is the sum of the perceived probability of each outcome, multiplied by the desirability value of that outcome. In terms of warning compliance, the subjective effective utility of complying with a warning, U_{comp}, might be seen in the following terms:

$$U_{\mathrm{comp}} = P_{\mathrm{ncomp}} \times V_{\mathrm{risk}} - P_{\mathrm{comp}} \times V_{\mathrm{risk}} - C$$

where

P is the probability of the outcome, which in this case is risk of, for example, an injury;

P_{comp} is the risk of injury if the warning is complied with;

P_{ncomp} is the risk if the warning is not complied with;

V_{risk} is a value corresponding to the risk inherent in the task.

C is the cost

COST variables can include things like the amount of time or money required to comply, and can include factors such as the distance one needs to travel to comply. So, there are several main judgements to be done.

— **Fuzzy probabilities**: The question as to whether or not a given warning would be read and heeded must be phrased in probabilities. This can be formalized by means of the Fuzzy theory (Kreifeldt, 1992). The probabilities are given only in qualitative form such as “low probability”, “more probable than not”, etc. The total proposition can then be represented as a set of interrelated sub-propositions. Experts attach weightings to each probability or range of possibilities. With Fuzzy probabilities, it is possible to draw definite conclusions from indefinite sounding phrases. An example is the probability that someone would read a warning on a label of a product or in the manual accompanying the product or both.

— **Theories of conditioning:** Habituation represents a decreased level of responding to an eliciting stimulus (Bliss and Gilson, 1998). In typical signal response situations, the signal itself represents the eliciting stimulus and the ensuing response may include deactivating the signalling system. The signal is repeatedly associated with fear which reflexively leads to a protective response. This may explain the ‘cry-wolf effect‘, that, due to numerous false signals in the past, the association between the signal and fear is no longer present (broken association between the conditioned and unconditioned stimuli).

— **Multiple resource theory:** According to Wickens (1984), humans have cognitive resources at their disposal to apply to various tasks. If two tasks utilize similar resources, there is a greater likelihood that performance on one or both tasks will suffer. This framework is useful for investigating alarm response scenarios. Humans are generally engaged in a primary task when confronted with signals. If responding to a signal requires cognitive resources similar to those used for the primary task, performance on the primary task or on the signal response task may suffer.

The above theories all make significant contributions to the understanding of operator behaviour stimulated by emergency signal failure. It is probable that each of these theories may help to explain operator reactions to signal failure in particular task situations. The designer of warning systems should consider the presumed balance of risks by the user, his habituation and the multiple resource theory which involves different sensory modalities and signal codes.

1) The SEU model represents a simple derivative of the SDT model.

2.5 Design recommendations

From these alarm theories, several key points may be proposed when designing the entire warning system (Bliss and Gilson, 1998).

- To minimize the growth of operator mistrust, designers of emergency signalling systems must make every attempt to maximize signal reliability.
- Low signalling-system reliability may have deleterious effects of signal response speed, accuracy, frequency and response decision appropriateness.
- The ‘cry-wolf effect’ may take the form of degraded responses in some cases, or a cessation of responding in others.
- Emergency signal detection and evaluation are separate but interdependent aspects of operator behaviour.
- Operators may have a tendency to match their response rates to signal reliability; furthermore, they often respond at a rate slightly higher than the signal reliability rate
- When determining the acceptability of a signalling system, it is critical to consider responses to individual signals as well as performance on the ongoing, interrupted task
- Operator mistrust has interactive effects with task workload and alarm system reliability. Together, these things determine an operator‘s tendency to shift attention from primary task to signal
- The choice of warning code and modality has to be related to the characteristics of the situational information

3 Psychological and physiological aspects

The developers of warning systems must consider the human abilities, the variability of human actions and the impact, that these will have in terms of use of the system (Clement, 1987).

3.1 Human processing of warnings

The treatment of a warning needs some form of divided attention between the original task and the response to the warning. Because of the severely limited capacity of the human being to deal with incoming information at some stages of the analysis, only a small portion of the incoming information is selected for further processing (“attention”, Norman, 1969). There are two types of processing models which attempt to explain the limitations of attention: the serial process model and the parallel process model. The serial process model states that humans can do but one thing at a time and switch rapidly among the tasks (single-channel theory). The parallel process model states that humans can do a limited number of things simultaneously without switching (Norman, 1969). Final evidence for the validity of one of these models is still pending.

There are different stages of **human processing of warnings** with related aspects specified with (Kopf, 1998[2])):

- **Directing attention:**
  - recognition of the warning;
  - mental load, vigilance;
  - glance duration.

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2) The different aspects are not further described in the paper.

- **Situational orientation:**
  - glance duration;
  - situational distance to warning;
  - effects of command;
  - complexity of the actual situation.
- **Decoding of warning:**
  - sensorial modality;
  - code type.

The reaction time to warnings is at least a constant and depends on the number of options (Kopf, 1998; Wickens, 1992, see Figure 3). The fewer options are possible, the lower the reaction time is.

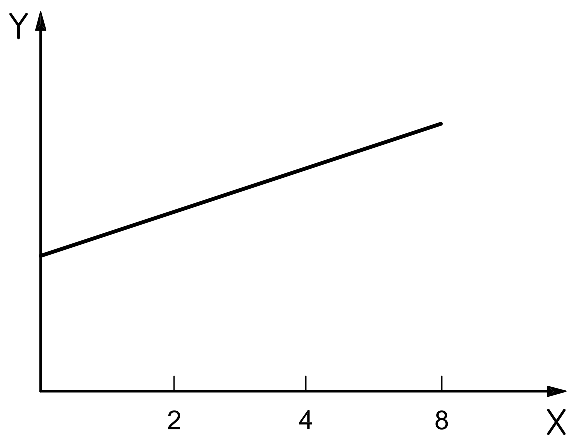
EXAMPLE

To judge the importance of the reaction time, the following example of a distance warning system with

range = 120 m, V_0 = 170 km/h, braking after warning = 6 m/s^2 is given. With

- a technical reaction time of 400 ms,
- a directing glance to scene of 100 ms,
- a reaction base time of 400 ms,
- a changing time of foot of 200 ms, and
- a braking response of 200 ms

the resulting collision probability would be 37 % (Kopf, 1998).



Key

X number of options

Y reaction time

Figure 3 — Reaction time as a function of number of options (Wickens, 1992)

3.2 Workload

As Zwahlen (1985) points out, a driver has some spare visual capacity on long straight road sections, during low traffic conditions and no adverse weather and when experiencing low navigational demands. Unfortunately, a significant portion of driving occurs in a multi-vehicle environment, adverse weather conditions, under traffic signal control, and on curves. In these situations, the information acquisition and processing rates and the eye scanning activities are high and the spare visual capacity is low. This problem is aggravated, considering that, for example, in a usual truck 180 different items of information can be presented to the driver (Färber, 1990).

The design and implementation of modern assistance and information systems in the vehicle must take into consideration the overall workload of the driver (Fastenmeier and Gstalter, 1997). Adding new assistance and information systems to the vehicle may actually relieve or add another burden onto the driver, i.e. the overall workload can be reduced or increased. Ideally, warnings should be issued only when the driver is not focusing on the road or when a dangerous change occurs rapidly in the position and speed of a vehicle in front (Horowitz and Dingus, 1992). However, as long as the collision warning system does not have information about the driver's state of attention, warnings are likely to be issued even when the driver is fully aware of the danger. For example, situations may occur when the driver is preparing to apply the brakes or is steering to avoid danger, while at the same point in time the collision warning system issues a warning which startles the driver. The driver then has to interpret the warning, thus his attention is shifted from action to a new unexpected stimulus. This adds to cognitive load and potentially leads to stress, delay in action, and incorrect responses.

An essential point is to keep the workload in a medium range to guarantee an optimal activation level (Fastenmeier and Gstalter, 1997). The driver himself compensates for additional or too low stress by compensation mechanisms (“Homeostasis of workload”). An additional burden may be encountered by having to interrupt not immediately necessary actions, such as a conversation. According to the Yerkes-Dodson law, the following cases can be distinguished.

— The driver has an insufficient workload, an additional burden is accepted and the overall workload shifts to the optimal performance.

— The overall workload is shifted beyond the performance maximum, then the driver looks for compensation strategies.

— The overall workload is shifted beyond the performance maximum and there are no compensation strategies, then the driver exerts himself more (more mental effort).

In moving to a future vehicle, in which the driver inputs the desired destination and allows the vehicle to proceed with little or no intervention, it becomes obvious that the role of the driver will change from primarily manual control to supervisory control (Schlegel, 1993). The major task will be one of monitoring the system and perhaps providing backup. Driver workload in this setting represents a completely different concept which presents new and difficult challenges to the engineering psychologist and human factors engineer. In this new environment, there may be little concern about entering the zone of high mental workload. It is likely that one will have to be alert to the boredom of insufficient workload (understressed situation).

There is a considerable range of drivers' capacity to cope with additional workload. New assistance systems can relieve the driver of workload or give the driver extra workload. In the case of extra workload, the driver has the potential of compensation or additional mental effort to counter this burden. Warning systems should fall into the category of "relieving", i.e. the overall workload is decreased and hazards are efficiently encountered. Badly-designed warning systems should fall into the category "stressing", where one should have confidence in the driver to cope with this, for example, to ignore or to deactivate the warning. The conclusion, however, that all auditory warnings should have an off switch is doubted (Stevens, 2002). This is not the case now, for example, with seat belt warnings. To prevent an unnecessary burden, ideally warnings should not be issued when the driver is fully aware of the danger.

3.3 Expectancy

Expectancy refers to a predisposition to believe that something will happen or be configured in a certain way (Olson, 1993). All drivers have certain expectations, which are based on their exposure to practices in traffic engineering and observations of the behaviour of other drivers, which influence their behaviour.

Conversely, when something does not work as expected, the result can be annoyance, distraction, errors and damaged equipment. All facilities that are contrary to expectations require more signing to alert drivers and give them time for planning.

The principle of expectancy extends to the design of symbols (see 5.3.2.1). Good symbols make intuitive sense to the driver, and are easily learned and recognized.

In traffic engineering, two general types of expectations have been described: a priori expectations are derived from general experience and ad hoc expectations are based on recent information.

Dejoy (1991) argues that there is little data to suggest that even the best designed warning will override the beliefs and expectations that the individual brings to the situation. Warnings should not be expected to override such information.

In order to be effective, warnings must be compatible with driver expectations.

3.4 Further human factors, individual differences

- **Attention**: Instructions must emphasize the need for continuous awareness of important items, e.g. by bright colours (see 5.3.2.3), short and emotionally salient words ("DANGER", see "signal words" below), and location in a place directly in the line of sight (see 5.3.1.1).

- **Perception**: The capabilities and limitations of visual or auditory perception of users have to be considered. One can not assume a normal vision, especially because of the increased number of older drivers (see 5.3.1.2). The use of colour should be controlled so as not to eliminate legibility for the considerable number of colour-weak or blind persons (see 5.3.2.3).

- **Comprehension**: Warnings and instructions must be understood by the user. Only minimal requirements with regard to driver tuition, conceptual level, and so forth have to be fulfilled to obtain a driving licence. The use of symbols has the advantage of being comprehensible by those with limited literacy (see 5.3.2.1).

- **Context**: Whether an individual attends to something such as an instruction or warning depends upon other conditions in the immediate environment, such as other warnings, people, or equipment, other stresses and experience. A sign which is constantly present is likely to be ignored after an initial reading ("adaptation").

- **Memory**: Most people cannot process, store in memory, or recall more than a half-dozen or so ideas, concepts or operations at a time and some will have even lesser capabilities.

- **Age**: Older people tend to be less impulsive, slower in reaction time, less able to remember a lengthy series of steps, but better able to comprehend purposes for instructions. Because of their slower processing and reaction times, older drivers spend more time focused on the forward road scene and less time scanning an information system (Hanowski *et al.*, 1999). Given this scenario, older drivers may benefit more from an auditory alert.

- **Education**: Better-educated people tend to be able to draw inferences more accurately and quickly, but are less likely to pay attention to simple instructions.

- **Fatigue**: Individuals tend to drive at a performance peak for a while and gradually become more and more error-prone the longer they have been driving and other factors become more important. Fatigue makes it important to emphasize warnings that are appropriate after extended periods of driving.

— **Learning**: An individual user often has minimal or no prior experience with a warning system. Thus, warnings that do not depend on prior learning for their comprehension, have the maximum chance of being understood. Experienced users should have the opportunity of skim unnecessary or known information.

Human ability and its variability have to be considered when conceiving warning systems, such as limitations of attention, perception and memory and the influence of the context, age, education and fatigue. Warnings should not depend on prior learning.

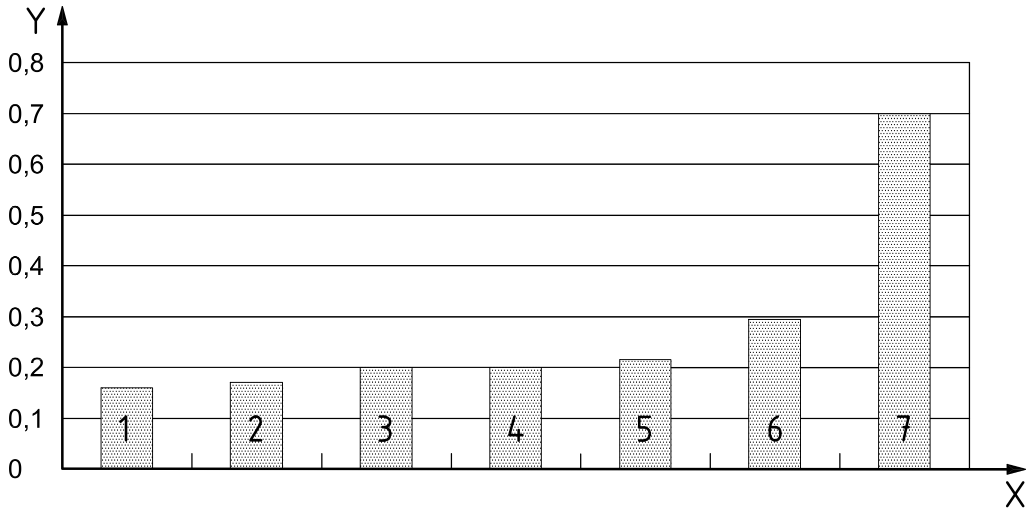
3.5 Recommendations

The basic properties of the "subsystems" of the human being, which have to be considered in developing warning systems in vehicles are (Stevens, 2001):

1. **The considerable human variability in height, reach and strength. Design needs to be such that systems are physically big enough for a large male to use yet are still usable for a small female who may have limited strength and reach (see 5.3.1.1).**
2. **Human performance in sustained attention tasks is poor in comparison with machine sensor systems. Warning systems should be designed not to be reliant on the driver maintaining a continuous awareness of the system state or road conditions.**
3. **People can detect detailed information in a relatively small area in the direction they are looking, the visual area outside of this 'foveal' region is more sensitive to movements and flashing lights and can involuntarily attract the drivers' gaze.**
4. **People have limited colour recognition. Too many colours in warning system displays should be avoided to support good discrimination of information. Preferably, three distinct colours should be used and not more than ten (see 5.3.2.3). Blue/green or white/yellow combinations should be avoided.**
5. **The vehicle is a relatively noisy environment and human hearing decays with increasing age, particularly at high frequency. Caution should be adopted in the pitch, frequency and use of auditory warnings (see 5.3.1).**
6. **Humans can react quite slowly to warning systems. One must provide reasonable time for the human being to respond to a signal. Under optimal circumstances, assume 1 s is required. More realistically provide 3 s or no need to respond in a rapid time frame.**
7. **The driver's ability to respond appropriately to warning systems operations will be affected by their fundamental level of driving task capability. The warning systems should not compromize driver safety particularly during periods of high task workload (see 3.2).**
8. **Some individuals adopt a level of risk that is personally acceptable. If the situation is perceived to be safer, they will undertake riskier activities, for example, faster driving and shorter headways. Design of warning systems should recognize the variation in personally acceptable levels of risk.**
9. **Humans have limited short-term memory. Systems should not require the user to remember or recall more than seven items in order to operate an interface or resume operation of the system.**
10. **Errors will be made by users and should be considered in the system design. Warning systems should be designed to be tolerant of human error, for example, probability of errors of commission of 10^{-3} with reasonably complex tasks, little time available.**
11. **Humans have automatic reactions and expectations when interacting with machines and with the environment. Warning systems should allow for these such that controls and displays behave in a manner that meets with expectations (see 3.3).**
12. **Human beings and machines both have strengths and weaknesses. Allocate functions between the human being and warning systems to exploit the tasks that each can undertake effectively to optimize overall system performance and enjoyment.**

4 Sensorial modality

For the application within automobiles, optical (sight, visual), acoustic (hearing, auditory) and tactile (touch, tactile) displays have to be differentiated. Figure 4 shows simple reaction times as a function of sensorial modality. It indicates that the basic reaction times are relatively similar for most of the senses, except for smell and pain (not included here are the different signal and processing times). Hearing and touch result in the shortest reaction times.



Key

X sense modality

Y reaction time, in seconds

1 hearing
2 touch
3 sight
4 cold
5 warmth
6 smell
7 pain

Figure 4 — Reaction times dependent on sensorial modality (Woodson, 1981)

Nowadays, most of the information is presented visually because the eye produces the most sophisticated messages from the environment (Rühmann, 1981). However the eye is already highly burdened by driving the vehicle.

Multiple-resource theory proposes that attentional resources differ along several dimensions, including stages and codes of processing, as well as input/output modalities (Wickens, 1992, see 2.4). Cross-modal task and information presentation should therefore lead to more efficient processing and improved task-sharing performance. In tasks like flying or driving with high visual workload, information should be distributed across various sensory modalities, including the auditory and tactile modality.

Information about the vehicle and the environment can be displayed to a certain degree through the auditory modality (see Clause 6). This comprizes simple signals as well as speech output. Auditory information is perceived quickly and reliably. Additionally, spoken speech can include instructions for the driver. So, auditory information is primarily suited for all kinds of warnings for the driver.

The choice between visual and auditory information presentation depends on the physical properties as well as the physiological and psychological attributes of both sensorial channels. Geiser (1990) gives an overview of the suitability of visual and auditory displays for different needs (see Table 4).

Table 4 — Overview of the suitability of visual and auditory displays for different needs

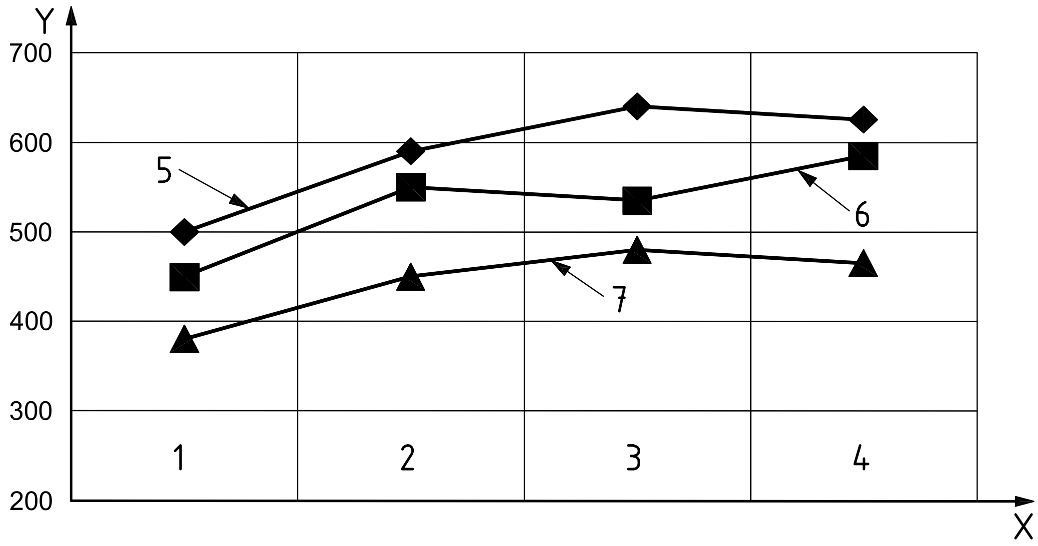
Visual display suited for (needs)	Auditory display suited for (needs)
Information-dependent characteristics	
Many and long messages	Few and short messages
Complex messages	Not too complex messages
Spatial and temporal information	Temporal information
Discrete and continuous information	Discrete information
Temporarily and spatially free access	Needs immediate listening or repetition
Simultaneous or sequential information transfer	Only for sequential information transfer (needs priority)
Not very urgent information	Important information (conspicuousness)
Environment-dependent characteristics	
Restricted user angle position	Free user angle position
Restricted user distance	Restricted user distance
User specific information transfer	General information transfer
Needs display space	Does not need display space
Influenced by bad illumination	Influenced by noise
User-dependent characteristics	
Dependent on tiring	Resistant against tiring
Sensible to additional activities	Insensible to additional activities
Does not annoy	Can annoy

Tactile information concerns the touch and motion senses of the human being. Static tactile information is used to specify controls and their status by forming the surfaces. Dynamic tactile information is suited for warning messages, which need immediate attention by the user (see Clause 7). Tactile feedback can be realized by vibrations or a specific power-distance-characteristics, such as the accelerator pedal.

Tactile information is more quickly and accurately detected and processed than visual and auditory information, especially when additional tasks are performed (Johnston, 1972; Benningsen, 1985; see Figure 5).

The complex reaction time to tactile signals is 20 % to 30 % [3] faster than for visual or auditory signals, not depending on the code of additional tasks. For this reason, more tactile messages should be fed back to the driver.

3) The complex reaction time includes the above mentioned signal and processing time, which dissolves the apparent contradiction to the results of the Woodson data (1981). Furthermore, the study of Johnston (1972) included additional tasks, which were auditory and visually coded.



Key

X additional task
Y reaction time, in seconds

1 no
2 auditory
3 visual
4 combined
5 visual
6 auditory
7 tactile

Figure 5 — Reaction times with warning devices of different modalities dependent on modality of an additional task (Johnston, 1972)

The general conclusions from the comparison of visual and auditory displays for warning messages in vehicles are that short important warnings are basically better presented by the auditory modality, if complex information content can be transferred later or visually, the message is repeatable, the signal-to-noise ratio is sufficient and if the annoyance effect can be reduced. Similarly, in the context of vehicles with complex subsystems, high priority should be given to tactile warnings. Detailed experimental results are given in Clause 9.

5 Visual warning signals

Visual information can be classified according to its content (Färber and Färber, 1987).

— **Actual value display**: An actual value display presents the momentary value of a system parameter, e.g. speedometer.

— **Nominal and actual value display**: A nominal and actual value display presents the nominal and actual values of a system parameter together, e.g. revmeter.

— **Difference display**: A difference display presents the difference between the nominal and the actual value of a system parameter. Control deviations can be displayed magnified. A possible example is the RPM deviation from an economic value.

— **Synthetical display**: Synthetical displays consider several single data and derive one piece of integrating information of higher value for the driver, e.g. driving time to destination.

— **Command display**: The command display delivers concrete instructions telling the driver what to do. The machine is the "head", the driver the "hand". The driver does not dispose of all information but is told exactly what to do, e.g. navigation instructions.

The visual information may represent the informational part. The alerting cue has to be added by appropriate design (see 5.3).

5.1 Psychological/physiological bases

In difficult driving situations, the information acquisition and processing rates and the eye-scanning activities are high and the spare visual capacity is low (Zwahlen, 1985). One of the main techniques to assess visual load is to explore the visual activity.

A model of visual sampling has been provided by Senders *et al.* (1967): the idea is that drivers sample the forward view and that between samples there is an uncertainty build-up with time. Eventually, an uncertainty threshold is reached and the driver must then glance to the forward view. When using an in-vehicle device, there is a minimum-tolerable-information sampling frequency for each given type of road and vehicle speed. If the sampling frequency is below this minimum, drivers immediately decelerate to compensate for lack of forward view information.

Wierwille (1993) screened several studies with respect to visual glance times and number of glances for a variety of tasks (see Table 5).

Table 5 — Visual glance times and number of glances for a variety of tasks

Device	Glance duration s	Number of glances	Total glance time s
Turn on radio, find station, adjust volume	—	2 to 7	—
Radio (generally)	1,2 to 1,3	—	—
Left mirror	1,0 to 1.2	—	—
Speed (check or exact value)	0,4 to 1,2	—	0,8
Destination direction	1,2	1,3	1,6
Tone control	0,9	1,7	1,6
Fan	1,1	2,0	2,2[a]
Correct direction	1,5	2,0	3,0
Fuel range	1,2	2,5	3,0
Zoom level	1,2	2,9	3,5[b]
Tune radio	1,1	6,9	7,6
Roadway name	1,6	6,5	10,4

[a] This figure was slightly corrected by the reporter with respect to glance duration × number of glances.

[b] This figure was slightly corrected by the reporter with respect to glance duration × number of glances.

In most cases, drivers do not sample continuously. There is a relatively narrow range of single glance times. On average, drivers do not allow their single glance times to exceed about 1,6 s, even for complex information gathering tasks. Instead, they return to the forward scene, attend to the driving task, and then return to gather additional in-vehicle information (see sampling model above).

But there is a relatively broad range of number of glances and total glance times. Gathering information for several navigation and certain conventional tasks (radio tuning, etc.) results in large visual demands.

Visual sampling depends strongly on age (Wierwille, 1993). There is a strong evidence that in-vehicle single glance times and number of glances increase with age because of deterioration of vision and slowing of cognitive processes. The mean glance length can increase from 1,0 s (for 18- to 25-year-olds) to 1,3 s (for 49- to 72-year-olds).

Any visual warning displays have to consider the visual sampling process of the driver. A certain range of number of glances and of total glance time should not be exceeded, even though the experienced driver is capable of distributing his glances among the forward and in-vehicle view. The design of visual warnings has to ensure a relatively fast reading even for older drivers.

5.2 Types of visual displays

At the beginning of this clause, visual displays were categorized according to their content. Visual displays can also be distinguished in respect of their codes (Galer and Simmonds, 1984; Geiser, 1990) (see Table 6).

Table 6 — Visual displays distinguished in respect of their codes

Visual displays	Explanation	Advantages	Examples
Analogue displays	The position of a pointer on the scale is analogous to the value it represents	Quick check reading, rate and direction of change information	Conventional speedometer
Discrete displays	Analogue displays where the readings are discrete rather than continuous	Quantity information without too many details	Fuel indicator
Digital displays	The information is presented directly as a number	Precise reading	Odometer
Alphanumerical displays	The information is presented as messages in full or abbreviated form	Detailed transmission of information, including instructions (see 5.3.2.2)	Fasten seat belt
Symbols	Symbols are graphical signs which transmit messages independent on speech	Independent on a specific language, space saving, etc. (see 5.3.2.1)	Hand brake indicator

Two types of visual displays can be differentiated: primary and secondary visual displays.

— A **primary visual display** should immediately and reliably capture the driver's attention. These displays should be as simple as possible and provide only the information necessary for the driver to resolve a crash situation. Alphanumeric displays and complex icons should be avoided. Primary displays should be located within 15° of the driver's expected line of sight and they should not be obscured by other visual displays or structures within the vehicle, e.g. the steering wheel.

— **Secondary displays** should be less conspicuous than primary displays. They should not distract the driver's attention from the primary display nor should they provide flashing indicators. According to MIL-STD-1472D, a driver should not be required to transpose, interpolate or translate displayed information, because, as a result of performing mental manipulations, response time will increase (NHTSA, 1996).

5.3 Design parameters

A driver has to receive and process information and react to it. These activities may be divided more elaborately into: searching, classifying, memorizing, supervising, comparing, calculating, etc. These processing phases depend differently on the characteristics of information, such as sign size, colour and arrangement. To differentiate among design parameters of information presentation, Geiser (1990) proposed the categories of information:

— sensorial-related parameters;

— coding parameters;

— organizational parameters.

5.3.1 Sensorial-related parameters

Sensorial-related parameters of visual displays concern those characteristics of a visual display which affect the "mere" perception of a visual signal by the eye (Geiser, 1990). There are many sensorial-related parameters for visual information, such as size, brightness and contrast. Their effect on the user can be subsumed under readability [4].

Extensive data on how to design visible and legible alphanumeric information to increase acquisition performance and minimize fatigue is currently available (Imbeau *et al.*, 1993). These are mainly quantitative data relating the isolated effect of each of the design parameters (size, contrast, colour, etc.). However, quantitative data about the combined effect of several of these parameters, as well as information on the interactions between these parameters, is scant.

It is well known that stimulus similarity has a deleterious influence on choice reaction time (Cohn, 1995). Research has shown that signals should have unique position, unique size and unique shape. In the following subclauses, two sensorial-related parameters, which are among the most important ones in the context of visual warning signals, are discussed: display position and sign size.

5.3.1.1 Display position

It is generally recognized that, as the angle between the forward view and the in-vehicle task increases, transition time for the eye also increases. Therefore, dynamic information to which the driver must respond immediately should be displayed as close as possible to the primary field of view. A position classification for controls and displays in vehicles considers the necessary head and body movements (Elsholz and Bortfeld, 1978) (see Table 7).

Table 7 — A position classification for controls and displays in vehicles (Elsholz and Bortfeld, 1978)

Priority	Field of vision	Head movement	Body movement	Reachability	Examples
		necessary for perception			
I	Primary	No	No	Fastened by seat belt	Oil pressure, High beam
II	Secondary	Partly	No	Fastened by seat belt	—
III	—	—	Yes	Before driving from seat	Telephone

4) "Readability" is used here for alphanumeric as well as for symbolic information. When (textual) words are used it includes that the whole word can be read, while "legibility" means the recognition of a letter.

Usually, most of the visual displays are located on the instrument panel. Here, they are relatively near to the forward line of sight and eye movements are possible without head movements. But information on the instrument panel can be obstructed by the steering wheel and peripheral vision (viewing the instrument panel and the vehicle's environment simultaneously is hardly possible, see below). Warning signals on the instrument panel have to be designed conspicuously so that they are perceived in due time.

Modern information systems are often positioned in the middle console where eye and head movements are necessary (Färber and Färber, 1987). While the observation of the instrument panel requires a viewing angle of about 15° below the forward line of sight, the viewing angle to instruments in the middle console is about 30° (Färber *et al.*, 1990). This results in longer reaction times to stimuli presented in the middle console. The conclusion of Färber *et al.* (1990) is that the middle console is possibly suited for well-designed pictograms (icons) but not for alphanumerical signs or text. Because of the large viewing angle, any warning signs at the middle console should be designed very conspicuously.

The position of displays within the vehicle is dependent on their importance and frequency of reading (see above) as well as on the level of perception. Two cases can be distinguished.

a) Information has to be recognized in detail and needs a fixation.

b) Information has to be detected and/or recognized roughly and needs no fixation.

In Case a) where information has to be recognized in detail, reading text and important information should be reached with one saccade departing from the main line of sight (Färber and Färber, 1987). There are (however not significant) shorter reaction times if they are centred in front of the driver as compared to left and right positions (Sauter and Kerchaert, 1972). The shortest recognition times are expected, of course, in head-up displays (see above).

Case a) has to be modified if colours have to be recognized. The colour vision field is smaller than that for achromatic signals and different for the different colours. For example, green objects of 25´ (25 minutes) size are not detected beyond a vertical angle of 15° from the main line of sight (red: 18°, yellow/blue: 22°).

In Case b) where information has to be detected or recognized roughly, such as rough reading of a speedometer or detection of a warning signal, the detection rate is steadily decreasing with greater distance from the forward line of sight (Geiser *et al.*, 1982). At an angle of about 15° the probability of recognizing a speedometer pointer is reduced to 50 % (other displays visible, see Figure 6), i.e. usual information in the dashboard can not be recognized peripherally but needs an eye fixation.

As shown in Figure 6, as the angle between the forward view and the in-vehicle task increases, transition time for the eye also increases. Moreover, accommodation time increases with the change of distance from the viewer and also with age. The accommodation process for instrument clusters usually takes between 0,3 s and 0,5 s. For older drivers, this is a strain and sometimes impossible (Knoll, 1997).

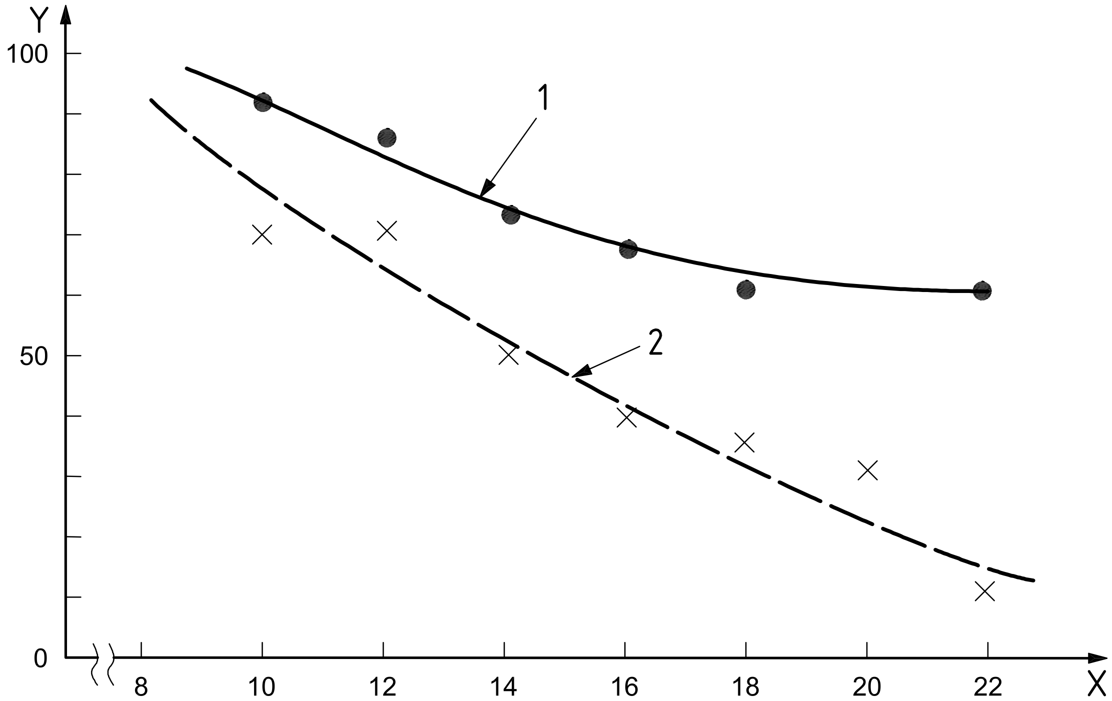
Finally, the further down from the forward line of sight a display is, the less likely it is that peripheral vision could be used to detect a hazard in the forward scene. These well-known time-consuming factors suggest that it is best to locate the in-vehicle task display as high on the instrument panel as possible, or even above it, and the focus distance to the in-vehicle display should be further away rather than nearer. To accomplish such objectives,

— head-up displays,

— other virtual image displays, and

— variable displays mounted near the top of the instrument panel

should be considered (apart from auditory displays, see Clause 6) (Wierwille, 1993).



Key

X angle, in degrees

Y percent

1 other displays covered

2 usual environment

Figure 6 — Peripheral perception of a speedometer pointer (Geiser *et al.*, 1982)

If a high level of attention is to be achieved, for example in the case of warnings, the obvious choice is to display this information with the aid of a head-up display (Knoll, 1997; Mutschler, 1992). The head-up display puts the information at a distance in front of the driver and includes it in the visual scene. This arrangement means that transition time and accommodation time can be minimized, while at the same time peripheral vision can be used to detect emergencies.

The advantage of the head-up display must be weighed against the disadvantages, namely possible distraction caused by its presence in the driving scene, possible obscuration of scene information “behind” the virtual image and very restricted information quantity (Mutschler, 1992). Whether the attention-getting effect (“compelling” information perception) is a disadvantage or rather an advantage depends on the information's urgency. For warning systems, the attention-getting effect (high position on the windscreen) and the avoidance of obscuration (low position on the windscreen) should be balanced.

A virtual image display is similar to a head-up display in that it places the image at a distance. However, such displays are usually in the upper portions of the instrument panel (Swift and Freeman, 1985). They produce an illusion for the driver that the display is deep in the engine compartment or near the front bumper and they reduce accommodation time.

Information placed near the top of the instrument panel has the advantage of allowing a variety of messages to be presented from a location, that rapidly becomes familiar to the driver.

The following table summarizes the characteristics of the positions of visual warning signals in the vehicle:

Table 8 — Characteristics of the positions of visual warning signals in the vehicle

	Instrument panel	Middle console	Head-up display
Disposable space	+	+	−
Conspiciousness	+	− −	+ +
Eye/head movements	+	− −	+ +
Adaptation/accommodation	−	− −	+ +
Avoid annoyance	−	+ +	− −

To catch the driver's attention, warning signals should be located very near to the forward line of sight. If no further accompanying auditory signal is given, they should be located at the upper parts, or upon the dashboard or even in a head-up display. Coloured steady warning signals have to be in the upper parts of the dashboard. Blinking signals — if present — could be positioned anywhere in the dashboard. If further recognition or reading of warning information is necessary, the usual distraction aspects of any visual information have to be considered.

With an auditory signal, the position depends on the informational content of the warning message to allow for peripheral vision or a sufficient change of visual focus. As for other visual displays in the vehicle, the display should be designed to keep accommodation and adaptation to a minimum, for example, with a virtual display.

5.3.1.2 Sign size

An important sensorial parameter for textual information is sign size. Sign size is usually defined in terms of subtended angle. This allows for differences in viewing distance by measuring sign height relative to viewing distance.

According to DIN Recommendation FNErg AA 4 Nr. 35 (1986) (Färber and Färber, 1987), the size of signs, in minutes, should be:

— steady signs: 18´

— changing signs for favourable conditions: 24´

— changing signs for unfavourable conditions: 40´

For example, for a distance of 70 cm under favourable conditions (relating to form, contrast, etc.), a changing sign should be at least 5 mm high[5)]. This holds true for the sufficient perception of a sign when being fixated (for the necessary alerting cues of a warning signal, other design parameters have to be considered, e.g. blinking etc., see below).

For characters (as a specific form of signs), the following recommendations exist (Galer and Simmonds, 1984):

— optimum size for scale markings for near error free reading: 15´

— viewed from less than 1 m: slightly > 15´

— primary digital instruments, e.g. speedometer: 18 mm

5) This corresponds roughly to the “James-Bond-rule” since sign height/viewing distance = 0,007.

A fully mature design could use enhanced size to highlight events which rarely occur but are highly costly (Cohn, 1995). Character or icon height can be increased to as much as 1° with proportional reduction of choice reaction time. Often, however, one requires a compact display, e.g. a 3×4 array which lends the appropriate compactness to the system. Even in that case adequate separation must be employed to prevent "crowding" from limiting visibility. The maximum area for efficient search is about 9° which limits the area of the display and correspondingly limits the size of components.

The height of warning signs and characters should consider adverse conditions, i.e. it should amount to about 10 mm. Alphanumerical warning information should have a size on the order of 20 mm. Size in itself adds to detectability but compromises the compactness of a display. A compromise has to be found between a sign size and compactness. Contrast can be increased to compensate for smaller character size, allowing a more compact display. Crowding of display information has to be prevented.

5.3.2 Coding parameters

Visual information can be coded by size, shape, colour, blinking, etc. or by combinations (redundant coding) like size/colour. In redundant coding, differentiating characteristics of codes depend on each other.

If absolute judgements have to be discerned, the following maximal numbers of code levels should not be exceeded (Geiser, 1990):

- line length: 4;
- line angle: 8;
- brightness: 3;
- colour: 5;
- blinking frequency: 3;
- size: 3;
- form: 1 to 100;
- alphanumerical signs: not limited.

5.3.2.1 Symbols, icons

Symbols are graphical signs which transmit messages independent of speech. They can represent objects, states, functions, events and instructions (Geiser, 1990). They are an alternative (or supplement) to alphanumerical signs. They provide an alphabet where each sign represents a significant item.

Symbols can be classified according to their proximity to realism (Geiser, 1990):

- image of an object without unnecessary details, e.g. a crossed cigarette for "Smoking forbidden";
- abstraction of facts by an analogy or an example, e.g. a wine glass for fragile goods;
- synthetical sign, e.g. a triangle for "Give way".

Conventional symbols with a low abstraction level are called "representational displays" or "pictograms" (icons), those with a high abstraction level are called "symbols". Both types are termed here as "symbols". The representational displays provide the user with a "working model" or "mimic diagram" of the process or machine, for example a sketched vehicle with open doors. They enable the user to observe the function of each part in relation to the whole, and to locate faults quickly, for example a vehicle diagnostics diagram (Galer and Simmonds, 1984).

The advantages of symbols are that the user does not need to have knowledge of a specific language, but he has to know the signification of the symbols. Often, symbols are not self-explanatory and have to be learned. In the automobile industry, there are over 100 pictograms, which are difficult to handle. Many pictograms, however, can be interpreted correctly by most users (Färber, 1990).

When summarizing the general advantages and disadvantages of symbols with respect to alphanumerical signs, the following can be specified (Färber and Färber, 1987; Geiser, 1990; Färber, 1990) (see Table 9).

Table 9 — General advantages and disadvantages of symbols

Advantages of symbols	Disadvantages of symbols
Faster found and recognized	
Need much less space than text	Too many symbols if many classes (“Hieroglyphics”)
Not bound to a specific language	Have to be learned
Higher range	
Better memorization	
Help for inner model	

DIN 70005, part 2 (1985) contains 107 symbols about passenger vehicles' systems and functions. There are 15 symbols concerning sight which are very similar to each other; these require knowledge about the functions of the vehicle and have to be learned (Färber and Färber, 1987). For example, a line across the window stands for wiping, a dotted line across the window means washing and a dotted line above the window means interval wiping.

ISO 2575 is the International Standard for symbols in vehicles. The symbols for ISO 2575 were investigated with respect to interpretability in a series of research activities (Green, 1993). Saunby *et al.* (1988) conducted a study to investigate the extent to which drivers understand the ISO symbols. 505 US drivers wrote the names of 25 symbols (free-response task) and then matched symbols with a list of control/display names (matching task). Only nine of the 25 symbols exceeded a 75 % criterion in the free-response task, as opposed to 16 in the matching task. The best recognized symbols were: horn, battery, turn signal, trunk, fuel and high beam. The worst recognized symbols were: rear and front fog light, choke, master lighting, windscreen (W/S) defrost, hazard and head lamp cleaner.

The conclusion of Green (1993) from this and similar studies are that drivers' understanding of several symbols has remained at the limit of acceptability. People over 50 and women have somewhat greater difficulty in identifying symbols. Moreover, there were country-specific differences.

The comparison between symbols and alphanumerical signs depends on the characteristics of both (Haller, 1979). Text is based on speech and is therefore encoded and processed in an auditory form. Symbols, however, are more visually processed which leads to shorter recognition times (see above), especially with large amounts of information (Steiner and Camacho, 1989). Since symbols exploit the given space better according to their two-dimensional characteristics, they have the double range as compared to text.

German visitors to a BMW museum were shown German words and symbols and were asked what they represented. Interpretation of the words was usually superior (Elsholz and Bortfeld, 1978). If the words are well-known, e.g. “Warnblinkanlage” and “Luft”, then textual representation is favourable. If the user is not familiar with the words, e.g. “Frontklappe” and “Heckklappe”, then symbolic representation is better. Ten or more days later, the experiment was repeated. Correct identification of the words increased from 81 % to 93 %. For symbols, the increase was 56 % to 83 %, respectively. Even after training, the identification of symbols was only slightly better than the initial response to words.

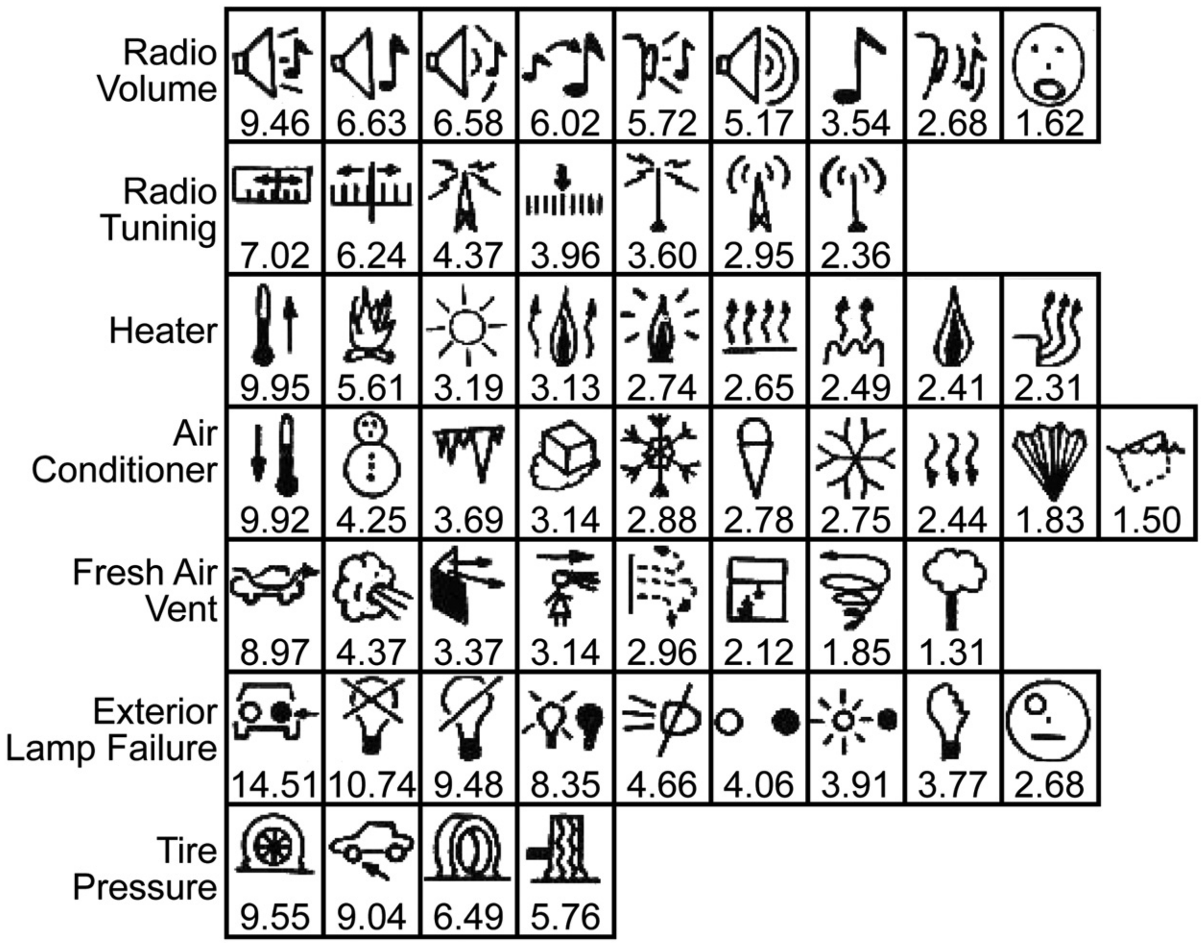
This experimental investigation was doubted by Färber and Färber (1987), who stated that the overall distraction effect and the adequacy of reactions should be taken as criteria for choice of an information code and not reading time. It is not possible, therefore, to generally recommend symbols or text. In the case of

- too much information for symbols with restricted "symbol alphabet",
- too much distraction by text, and
- some urgency

Färber and Färber (1987) refer strongly to speech output (see 6.4).

Words and abbreviations in foreign languages are less easily understood than the equivalent symbols. This is particularly important for internationally marketed vehicles, where native language barriers can decrease usability (Green, 1993).

Good symbols are detectable, discriminable from others, and meaningful to drivers. When symbols are well learned, detectability is the most important of these attributes (Green, 1993). To predict discriminability of symbols, several mathematical models have been proposed (Green, 1993). The meaningfulness of combined symbols depends much more on the meaningfulness of the system symbol than on the meaningfulness of the attribute (see Figure 7).



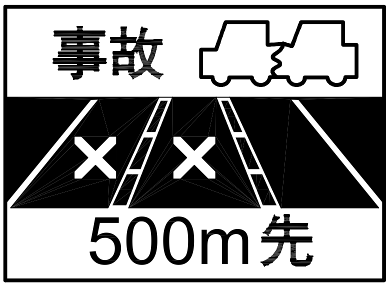
Symbol ratings from Green (1979a)

Figure 7 — Most meaningful symbols in Green (1979)

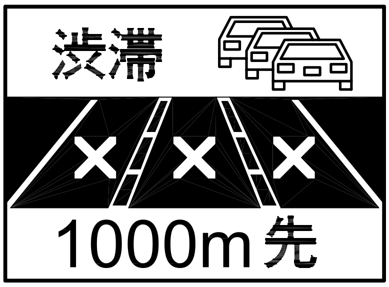
Only a few experiments on symbol learning have been conducted, typically testing factory visitors before and after a tour. In the above-mentioned study of Elsholz and Bortfeld (1978), correct identification of symbols increased from 56 % to 83 %, which shows the potential and necessity of learning the meaning of symbols.

Testing requirements for vehicle symbols have been debated within ISO TC 22/SC 13/WG 5. ISO 7000 requires 85 % correct matching tests where the risk in using a symbol is small, and 95 % when it is large.

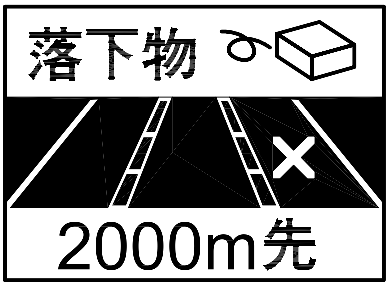
Nakamura (1995) built an experimental warning and information dissemination system. The system provides the driver with the road information detected on the road side and the emergency information received from vehicles to prevent collisions. Sketches of the road ahead with the free and blocked lanes as well as the crucial situation and the distance to it are displayed on a 6-inch LCD device (see Figure 8). The effectiveness of the display was evaluated from the driver's point of view by means of a comparative experiment with and without it (results were not reported).



a) Accident — 500 m ahead



b) Congestion — 1 000 m ahead



c) Fallen object — 2 000 m ahead

Figure 8 — Examples of screen display by danger ahead warning function (Nakamura, 1995)

The presentation of symbols for warnings in vehicles is critical. Indeed, they may be recognized faster and are language independent, but their significance can be completely missed because of lack of knowledge. The rarer the symbols presented, the higher the risk of misunderstanding. If symbols are used for warnings, they should be accompanied by textual or spoken speech for action instructions. Icons can relatively realistically represent the reality and counter the problem of low understanding of symbols.

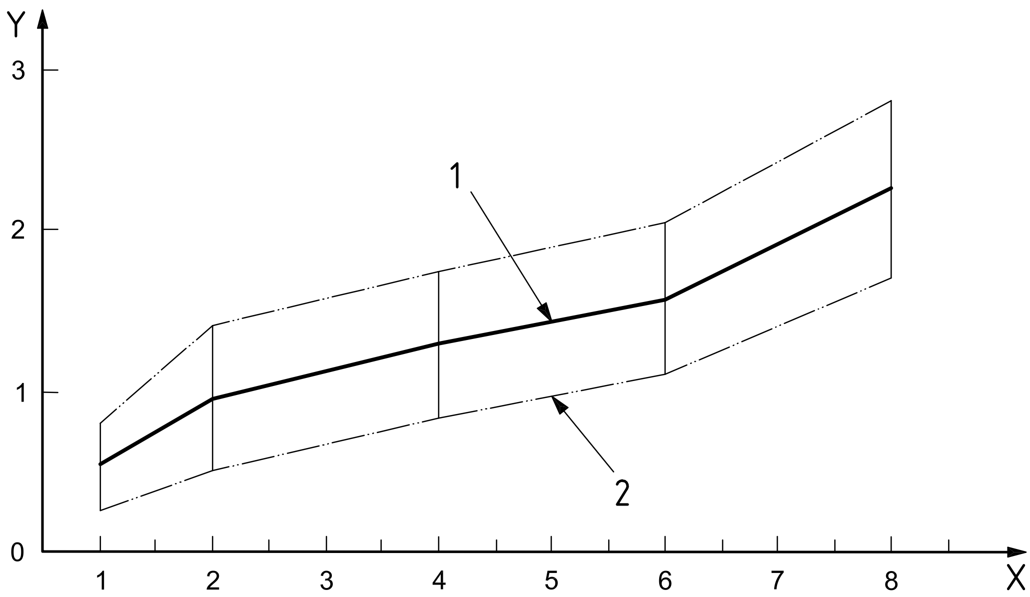
5.3.2.2 Textual warnings

The disadvantages of symbols are more or less the advantages of text, i.e. text does not need symbols and requires no additional learning for a native, educated reader. On the other hand, text needs more space and more processing time and is bound to a specific language (see above).

Voss and Bouis (1979) investigated different textual warnings as compared to speech output in a laboratory experiment with a simple tracking task (see Figure 9). The viewing angle below the forward line of sight was 30°, the letters 31´ (31 minutes) high (good readability). All messages were announced by a buzzer.

EXAMPLE “Stop immediately, oil temperature too high.”

The reading time was in the order of seconds and increased with the number of words in a message. The driving quality was markedly influenced by reading (see Clause 9).



Key

X number of words in the message

Y reading time, in seconds

1 mean

2 standard deviation

Figure 9 — Reading time as a function of message length (Voss and Bouis, 1979)

The study of Rickheit *et al.* (1999) concerned textual messages within the automobile environment. They investigated the comprehensibility of written messages of driver information systems with eye movement measurements. In Experiment 1, length, type, complexity, meaning of words and other characteristics of words were investigated with 125 authentic messages. Experiment 2 concerned the comprehensibility of sentences, for which length, type, verb position and other characteristics of 40 authentic sentences were studied. The results are presented together with those of other authors[6)].

Reising (1989) investigated expanded and abbreviated text for warning systems of fighter aircrafts. The following formats were tested:

a) abbreviated title of the emergency, e.g. ELEC SYS/MAIN GEN;

b) complete title within the checklist, e.g. MAIN GENERATOR FAILURE/ELEC RESET SWITCH-DEPRESS;

c) complete title with the checklist, plus the pictorial switch layout, i.e. CRT showing location of switch to be pressed.

Results showed that there is a definite advantage in using the complete checklist b) and c). Event time for the abbreviated checklist a) was significantly longer than for the other two displays. However, there was no difference in event time between b) and c). One possible explanation for this finding is that the pilots were reluctant to push switches without first reading the checklist display. Most of the pilots read the checklist because they wanted to know the severity of the flight emergency.

An extended survey of facilitators (see below) is given by Laux and Mayer (1993). Though facilitators are instructions and warnings to support vehicle users in nondriving functions their conclusions can be generalized in a restricted way for warnings in moving vehicles. The results are presented together with those of Rickheit *et al.* (1999) and Clement (1987).

Materials which assist users in their interactions with complex devices or systems are called facilitators (Laux and Mayer, 1993). Two kinds of facilitators can be distinguished.

— **Instruction**: An instruction communicates procedures and helps the user to determine when to act; it tells what to do and why.

— **Warning**: A warning communicates that a hazard exists, what the hazard is, how to avoid the hazard and the consequences of failing to take the proper action.

Good facilitation by text requires that complex technical information be translated into plain German or English, etc. It also requires facilitator developers to know exactly what needs to be communicated and communicate it in ways that users will understand, believe and use (see Figure 10, see 3.4).

Comprehensibility: One of the most important considerations for facilitator developers is the level of language to be used when communicating to a diverse group of users. For example, it is estimated that at the present time, 10 % or more of the adult population of the US cannot read (Miller, 1988). For users who do read, but whose reading ability is limited, it is important to keep the readability level of the text as low as possible (see 3.4).

The following list of rules and recommendations assures comprehensibility with a minimum of visual effort (number and duration fixation) and cognitive effort (Miller, 1988; Rickheit, 1999; Clement, 1987) (see Table 10).

6) The authors interpreted their results as “must”, “should” and “can” recommendations.

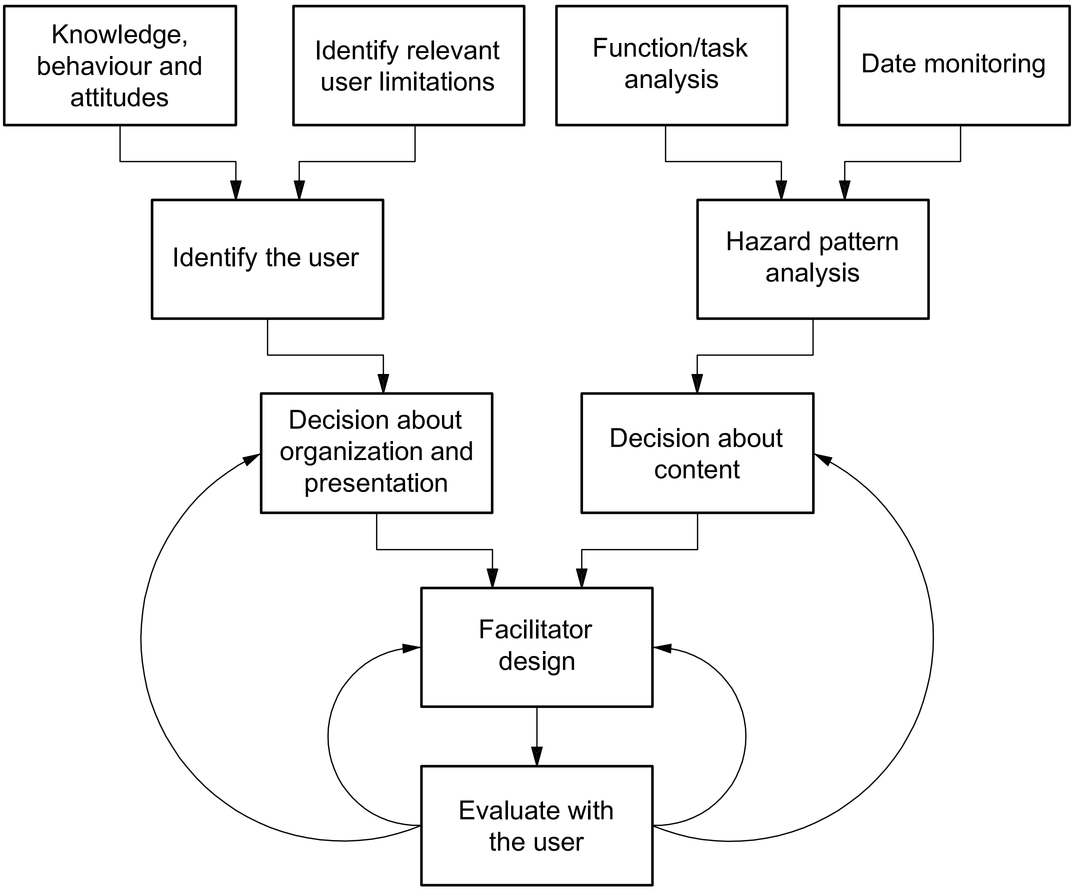


Figure 10 — The facilitator development process (Laux and Mayer, 1993)

Table 10 — Rules and recommendations (Miller, 1988; Rickheit, 1999; Clement, 1987)

	Rules for words	**Explanation**	**Recommendations**
Must	..must be short	Few letters	8 letters optimal; 16 letters acceptable
Should	..should be concrete	Relate to perceivable objects	As few abstract words as possible; at least one concrete word
	..should be frequent	Occur often in texts, no technical words	Should occur in a lexicon
Could	..are better if simple	Few components	1 component optimal; 2 components acceptable
	..are better if specific	Denote precisely	Few general words; no message with exclusively general terms
	Rules for sentences	**Explanation**	**Recommendations**
Must	..must be short	Few words	6-7 information-carrying words; 10 words altogether
Should	..should be redundant	Well predictable	Benchmark-test
	..should be simple	Few single statements	1 elementary statement optimal; 4 acceptable
Could	..can include a negation	If certain situational and cognitive conditions are given	One negation maximum

To increase comprehensibility, keep the message straightforward: use concrete rather than abstract language (say “flame” or “spark” instead of “source of ignition”), use the active voice (say “turn the dial”, not “the dial should be turned”) and tell the user what to do instead of what not to do (say “place the device in location B” not “do not put the device in location A”).

Differences in people are one source of the ambiguity of words. Another related source of ambiguity comes from the fact that words have different meanings in different contexts.

Facilitators provide three basic types of information: general information, procedural information and critical information.

— **General information**: This includes naming parts of the vehicle and explaining what they are for. Devices and processes should be named by terms which are meaningful to the user (‘user-preferred terms’).

— **Procedural information**: This information contains instructions on how to perform non-driving functions. This requires that the users know the names of the parts and devices involved and how they work.

— **Critical information**: In order to interact safely with a vehicle, users must also possess “critical knowledge” about each of the functions. This is specific information, critical to understanding how to perform that function safely.

The communication function of a warning is to alert users to the presence of a latent hazard, let them know how hazardous it is, and tell them what to do to avoid the hazard and what will happen if they do not act appropriately. Safety experts agree that all warnings should include:

a) a signal word conveying the intensity level of the hazard;

b) a hazard statement which tells what the hazard is;

c) a consequence statement;

d) a safety instruction message.

Signal words: The principal function of the signal word is to attract the users' attention to the hazard and indicate to him or her at a glance just how severe the hazard is. ANSI standards and those written by other hazard communicational specialists have made the following signal words standard for communicating hazard intensities:

— DANGER: immediate hazard which will result in severe injury or death;

— WARNING: hazard or unsafe practice which could result in severe injury or property damage;

— CAUTION: hazard or unsafe practice which could result in minor injury or property damage.

Statement of the hazard: The statement of the hazard can be in text format or in pictorial/symbolic form. The hazard statement must state the hazard in terms the user can understand, which, again, is best determined by user testing.

Consequences: A warning should also inform users of what can happen if they do not follow the safety instructions. It is important to spell out the specific consequences for most hazards, and it is important to communicate these consequences without trying to minimize the risk.

Safety instruction message: The instruction message can be in text format or in pictorial form. The instructions must state the actions necessary to avoid the hazard.

Textual warnings in vehicles should be used and designed specifically for vehicles. There are clear rules as to how to design textual warnings. They should be preceded by a tonal signal, be concrete, simple and should include not more than a few words. The text must be comprehensible to the typical user and clearly indicate the hazard level and statement as well as the consequences. Critical and procedural information should be distinguished; such information may be presented separately. Abbreviations should not be used.

5.3.2.3 Colour

The colour code has some specific advantages when several pieces of information are displayed and have to be distinguished, i.e. clarity, conspicuousness, less tiring (Christ, 1984). Concerning recognition accuracy, colour is superior to brightness, size and form, but inferior to alphanumerical coding (Geiser, 1990).

In search tasks, however, colour is superior to all other codes, redundant coding included (Christ, 1984). The more information elements, the more marked this advantage is. But the condition is that the colour of the target is known and not too many items are of the same colour.

There are contradictions between the objective and subjective findings of experiments. Coloured presentation has been judged to be more efficient by subjects, but was actually memorized more poorly than information being coded in another way (Karner, 1975).

However, colour coding should be avoided if there are many element classes, an unfavourable illumination, a small viewing angle and if the information is at a peripheral position (Geiser, 1990).

The brightness sensitivity of the eye is greatest at a wavelength of 555 nm (green) (Galer and Simmonds, 1984). However, this does vary according to whether the eye is dark-adapted (shift to blue-green) or light-adapted (shift to yellow-orange).

Not more than 5 colours should be used: red, orange, yellow, green, blue (Chapanis and Kinkade, 1972). There is a stereotype interpretation of specific colours in vehicles (see Table 11).

Table 11 — Interpretation of specific colours in vehicles (Chapanis and Kinkade, 1972)

Colour	Signification
Red	Danger
Orange	Warning
Yellow	Caution
Green	Normal operation
Blue	High beam

The colours red and orange should be reserved for danger messages.

A more recent study, however, called this widely-accepted association between colour and level of hazard into question (Leonard, 1999). Experiments revealed that the only colour on warnings that is well associated with risk is red. Red tends to be regarded as appropriate at least twice as frequently as the other colours orange and yellow. Using red on all warnings could, however, dilute the effect with more serious warnings. According to Leonard (1999), a conclusion is that shape or other graphical codes may serve better than colour to convey level of risk.

For warning signals the colour code is especially well suited because of its conspicuousness and still-accurate recognition. Care has to be taken that coloured signals are not too far from the forward line of sight, e.g. in the case of the dashboard, they should be located at the upper edge. At the lower edge, they are outside the colour field of vision.

About 8 % of males and 0,5 % of females have some form of colour blindness. Three levels of colour deficiency are recognized (Olson, 1993):

- **Anomalous trichromats** (“colour weak”): Perception of one or more colours is less than normal;
- **Dichromats**: Inability to distinguish one of the primary colours (2 % of population);
- **Monochromats**: Inability to distinguish any colours, seeing only in shades of grey (0,003 % of population).

Colour deficiencies are of concern in the design and operation of traffic and vehicle systems because of the wide use made of colour coding. They should be countered by redundant coding, i.e. the coloured signs including other codes beside colour.

If lettering is coloured (without the necessity of classifying on the basis of the colour and without distinguishing between elements), then the optimum for the bright- and dark-adapted eye is yellow-green (534 nm) and the optimum for the colour field of vision is yellow (Färber and Färber, 1987).

If coloured signs are displayed on coloured backgrounds, then the characteristics of the human vision for colour contrasts have to be considered. The best search results are attained when the colours are not adjacent on the colour scale. Emphasis should be laid on avoidance of the following colour contrasts: green/red, green/blue, yellow/red, yellow/blue, violet/red (Radl, 1980).

General rules for the number of colours in avionics displays are given by Krebs and Wolf (1979), which are shown in Table 12 together with the pros and cons of colour.

Table 12 — General rules for the number of colours in avionics displays (Krebs and Wolf, 1979)

Advantages	Disadvantages	Recommendations
Good detection within many objects	Subjectively overestimated	No use of additional colours if not necessary
Good classification with restricted object categories	Bad classification with many object categories	As few colours as possible; not more than 5 colours
Good for grouping and clear arrangements	Bad recognition with unfavourable illumination	
Pleasant presentation	Bad recognition in the periphery	

Green should be used to indicate that the device is on and has passed diagnostic testing; red and amber should be used to indicate that the device is turned on, but is not functioning properly (NHTSA, 1996).

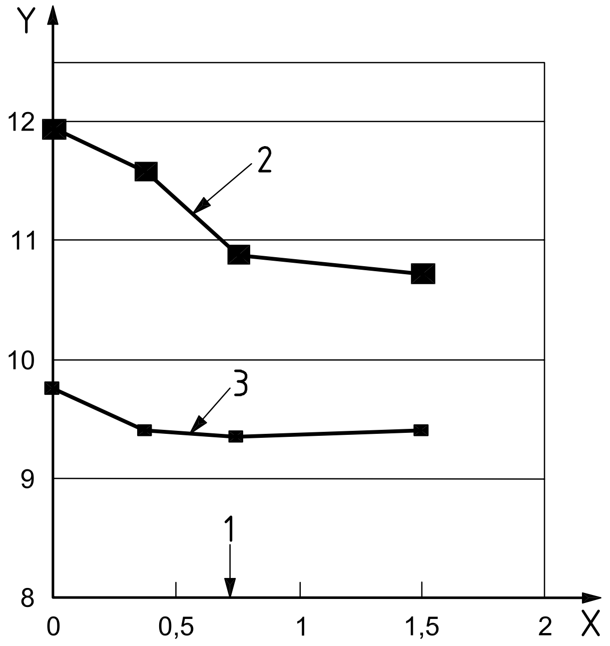
5.3.2.4 Blinking, apparent motion

The blinking code consists of a periodical turn on and off of binary signals. It is very conspicuous. Blinking draws the attention of the observer because the eye periphery is very sensitive to brightness changes (Geiser, 1990). Static objects, which cannot be perceived beyond 20° from the main line of sight, can be detected if they are blinking.

Flashing signal lights are detected more quickly than steady signals when all other background lights are steady, but the advantage is lost if only one background light is flashing (Boff and Lincoln, 1988).

Hopkins and Parseghian (1997) evaluated active warning signs designed to portray potential conflicts at unsignalized intersections. Diamond and rectangular shapes with a range of symbolic conditions were tested, including arrow and car icons that were presented in both static and flashing or animated conditions. Signs at the intersection warned stationary vehicles of oncoming traffic, while signs on the major road warned drivers of traffic in the intersection. The purpose of the signs was to provide drivers with supplemental information about traffic conditions. Objective performance measures showed the flashing version to be superior to static versions. The alerting value of the flashing appears to have resulted in more conservative speed control behaviour on the part of the driver/subjects. In particular, the flashing version of the two car icon sign resulted in a significant driver deceleration response relative to other steady and flashing conditions. Signs with car icons obtained the best rank order ratings from the driver/subjects.

Other authors studied the visual conspicuousness of open-level crossings with automatic flashing lights. Subjects had to identify the colour of the signal lights as fast as possible, while performing a tracking task at the same time. The flashing frequencies were ½, 1 and 2 times the standard frequency of 0,75 Hz. There was a small effect of flash frequency with respect to rise time to identification. It can be seen that this effect is primarily due to the reduction in identification time between the steady lights (0 Hz) and the standard frequency (see Figure 11).



Key

X flash frequency, 1/s

Y rise time to identification, in seconds

1 standard

2 white

3 red

Figure 11 — Rise time to identification

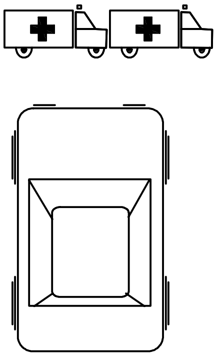
A blinking frequency between 2 Hz and 10 Hz is recommended (McCormick and Sanders, 1982). This range results from fixation period (low value) and flicker fusion limit (high value). If different blinking frequencies have to be discerned, a maximum of 3 should not be exceeded, however, this requires continued training on the part of the user (Geiser, 1990).

The main disadvantage of the blinking code is the danger of being annoying. Not more than 2 synchronously triggered elements should blink at the same time. Even for warning signals blinking should be designed very specifically for vehicles because of the possible annoying effect.

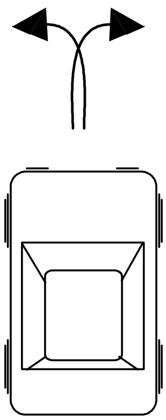
Movement is a well-established strategy for enhanced signalling in the periphery where this stimulus attribute particularly gets the attention of the driver and is more compelling (Cohn, 1995). But movement is also useful for central vision. Contrast thresholds are lower for moving images in both the periphery and the fovea. An optimally fast, sensitive response can be achieved by building motion into warning signals. The only evidence weighing against the use of motion is a worsened visual acuity for moving targets. To circumvent this problem, only the signal icon should be set into motion, and not correlated text (e.g. “Icy Ahead”).

The simplest implementation of a moving luminous warning signal is to put a target into apparent motion by the strategy of flashing two adjacent identical targets in sequence, i.e. stroboscopic apparent motion. This also satisfies the requirement to keep the warning signal relatively localized and at a predictable location. The target need not move more than its own diameter (or width) to achieve satisfactory motion.

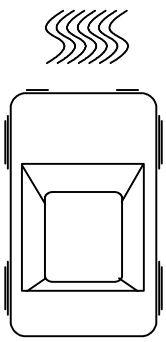
Figure 12 shows a sketch of the vehicle icon accompanied by examples of each of several possible moving warning signals.



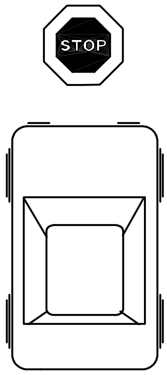
a) Emergency vehicle ahead.
(The icon jumps from side to side.)



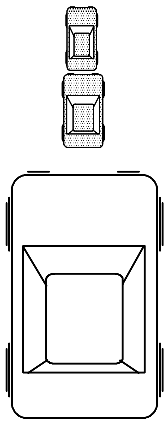
b) Too fast for curve ahead.
(The curved arrow is placed in apparent motion.)



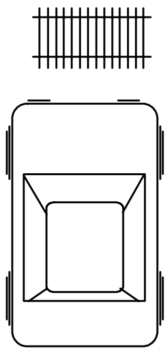
c) Icy roadway.
(Wavy lines march across from left to right.)



d) Too fast for stop-sign ahead.
(The stop sign expands or "looms".)



e) Disabled vehicle ahead.(The vehicle is in motion and "looms" toward the observer.)



f) Train in railroad crossing ahead.
(The railroad ties are placed in apparent motion.)

Figure 12 — Moving warning signals (Cohn, 1995)

In a task requiring simply the identification of one of four possible signals, an initial test resulted in a reaction time decreased by 55 ms to 87 ms, depending on the subject. It can be expected, that the distraction of a primary task such as driving, suboptimal ocular optics as might occur in elderly eyes, and superimposed visual stimuli as occurs in HUD imagery, would all tend to reveal increased superiority for moving warning signals (Cohn, 1995).

Flashing indicators should not be used to indicate the operational status of a warning device. Because of their superior conspicuity, flashing visual displays should be reserved strictly for imminent crash-avoidance displays (NHTSA, 1996).

Two alternatively flashing lamps placed a slight distance apart may also result in the phenomenon of stroboscopic apparent motion (Boff and Lincoln, 1988). If the stimuli are presented in the retinal periphery, the illusion is quite compelling, and the motion perceived may extend beyond the distance separating the lamps. Such apparent motion may be highly effective as an attention-getting mechanism.

Pros and cons as well as the recommendations for blinking are summarized in Table 13.

Table 13 — Advantages, disadvantages and recommendations for blinking

Advantages	Disadvantages	Recommendations
Very conspicuous	Annoying	Blinking frequency: 2 Hz - 10 Hz
Fast detection	Restricted information transfer	Optimal blinking frequencies: 3 Hz
		Maximum number of blinking elements: 2

Moving warning signals, can also enhance signalling in the periphery because of a higher attention-getting than static signals. It is possible that they reduce distraction of a primary task and are favourable for elderly eyes. The simplest form is a stroboscopic apparent motion.

5.3.2.5 Perspective representation

McGehee *et al.* (1992) examined the potential value of a front-to-rear-end collision warning system and made proposals for a perspective representation. When making judgements regarding depth, pictorial cues such as relative size and the visual angle of the vehicle ahead are one of the strongest depth cues (Levine & Shefner, 1991). As the distance of the vehicles decreases, the perceived size of the lead vehicle increases non-linearly, i.e. when a slowing vehicle is a long way ahead, the rate of size change is less than when it is close. Since drivers base closure rate judgements heavily on changes in visual angle, they often derive little information on the velocity of the forward vehicle or the relative velocity between vehicles (Mortimer, 1988). In addition, drivers often have difficulty gauging velocity differences and depth cues between themselves and the vehicle they are following (McGehee *et al.*, 1992).

A warning display could take into account driver brake reaction time based on the relative velocity of the two vehicles. By incorporating linear perspective and relative size information, this could be accomplished by graphically displaying headway and relative velocity information. Using this information could increase the driver‘s situation awareness or shift attention in time for a reaction to avoid an impending collision.

The perceptual weaknesses of a human being to assess front-to-rear-end collision situations could be reduced by a warning system with a display which indicates headway/following distance and the change in velocity of the forward vehicle. In addition, it could take driver brake reaction time, linear perspective and relative size information into account.

5.3.3 Organizational parameters

5.3.3.1 Information structures

In addition to the sensorial and code aspects, there are organizational parameters of information displays (Geiser, 1990). The spatial, temporal and content related structures of a technical system have to be mapped onto the display according to basic psychological rules. For example, the spatial structure of information should consider the Gestalt theory rules (Metzger, 1966).

Tullis (1990) outlined and defined four characteristics of display density that affects alphanumeric display format:

a) overall density,

b) local density,

c) grouping, and

d) layout complexity.

Overall density is the number of characters displayed or the percentage of total character spaces available. A general rule for overall density is to minimize the total amount of information on a single frame. Local density refers to the number of filled character spaces near each character. Spacing breaks up information into logical segments and provides structure. Grouping is the extent to which items form well-defined groups. Guidelines pertaining to grouping recommend that similar items be distinctly grouped. Finally, layout complexity is the extent to which items follow a predictable visual arrangement. Based on the location of some items on the screen, users should be able to predict the location of other items.

Hanowski *et al.* (1999) conducted a field experiment to investigate first the benefits and costs of using an In-Vehicle Information System (IVIS) when the driver is confronted with unexpected situations. The IVIS used in this study included 3 in-vehicle subsystems that provided signing, navigation, and warning information. The second research question was to clarify the impact of IVIS information density on driver behaviour and performance. Both the low-density and the high-density display conditions incorporated a warning system that alerted the driver to the planned events. The low-density condition included signing and warning systems, and the high-density display included signing, warning, and navigation systems. When new information was presented on the display for any of the subsystems, an alerting tone (“beep”) lasting 0,45 s was given.

No difference was found between the low-density and the high-density displays, suggesting that time to complete an event was not affected by display density. The results of an analysis of variance indicated that time to notice the warning message was not measurably affected by information density.

Experimental investigations resulted in recommendations for the spatial arrangements of a lot of achromatic symbolic information (Tullis, 1990): searching time increases with amount and extent of information and it decreases with increasing grouping. Overall density should be 15 % to 60 %, the higher percentages will increase search time. Group size should be 5°.

The fisheye principle means that a human being organizes his information by using a board with global context and a board with local details. He zooms in and out to have more details (but less perspective) or a better perspective (but fewer details). This holds true for spatial as well as for temporal structures (Geiser, 1990).

Different scales should be arranged consistently, e.g. the critical values of the fuel/oil pressure indicator are the left-hand side and the critical values of oil/water temperature are on the right-hand side of the scales (Färber and Färber, 1987). This can be improved by a horizontal arrangement of the (horizontal) scales so that the critical values are on the outward parts of the scales.

Visual warning systems have to be structured spatially and temporally in relation to the content. The organizational rules of visual information arrangements have to be observed, i.e. grouping, consistency, etc. Aspects of density and layout complexity have to be considered. There are preliminary results as to what degree different display densities influence the completion time of tasks. An approach to distinguish between alerting and informational aspects of a warning could be the "fisheye" principle.

5.3.3.2 Prioritization

If a variety of functions is to be presented in the same space in the panel, then a system of priority rating must apply. Otherwise hazard warnings may be blocked from appearing, by, for example, fuel economy figures being shown in the same space (Galer and Simmonds, 1984).

A priority classification will consider traffic safety/operation safety/economy, etc. and time criticality (Färber and Färber, 1987). This seems to be a useful approach for considering the more or less time critical warning systems. Without additional auditory signals the visual warning messages have to be given a high priority because of their importance and possibly because of their time criticality. The problem is the removal from groups of control/display belonging originally together. The intuitive association of a warning signal to the equivalent system is impaired.

The effects of visual display qualities on perceived criticality and urgency could be considered to present the warnings. Driver's subjective impressions were quantitatively clarified as interval scales according to differences of colour-luminance, intermitting of light, and visual size (Uno *et al.*, 1997, 1999), e.g. more luminous, shorter intermittent cycle, lower blinking rate and larger visual angle display induce higher level of perceived criticality and urgency. These researches also revealed that the physical properties give more dominant effects on driver's impressions, compared to differences among message words.

Priority of displays can be indicated by different codings, for example, position, colour and accompanying auditory signals. Concerning colour, it is usual for red and yellow to be used for warning, green and blue for information in vehicles (Galer and Simmonds, 1984, see 5.3.2.2).

Controls and displays should be positioned in relation to their importance, frequency of use and other aspects (see 5.3.1.1). High priority displays should appear in the primary space on the instrument panel where all drivers can see the display readily (Galer and Simmonds, 1984). Ehlers (1980) classified the controls according to a combination of use frequency/importance and prescribed by law/necessary for driving/comfort and allocated them to different areas in the vehicle. This, however, can disrupt functional groups and increase distraction, e.g. controls for the outside mirrors in the lower part of the middle console (Färber and Färber, 1987).

Multiple visual warning messages have to be prioritized according to a priority classification, especially if they are to be presented together with other visual displays in the same space in the panel. There is a sufficient number of possible codes appropriate for prioritization, primarily position and colour.

5.3.3.3 Integrated displays

An integrated system permits the reduction of the number of isolated displays and controls (Imbeau *et al.*, 1993). Whereas status indicators should always be displayed at the same position, warning messages can be concentrated onto a master caution (master alerting, master warning). A centrally-positioned general warning display is detected more accurately than peripherally positioned ones, even more so if it is blinking. Master cautions are used successfully in avionics systems. Since the master alerting signal can be visually or auditory, this concept is presented more generally in 8.5.

Peripherally located warning lights are detected with greater reliability when there is a central master light than when there is no master light (Boff and Lincoln, 1988). The response time (RT) to peripheral lights is faster with a central master light illuminated (RT = 2,8 s) than without a master light (RT = 3,3 s). Peripheral lights are detected eight times more often with a central master light illuminated than without a master light (27,4 % vs. 3,4 %).

Siegel and Crain investigated the optimum methods for presenting cautionary-warning information to aeroplane pilots. In several experiments, multiple compensatory tracking constituted a primary task, while response to various cautionary-warning signals constituted a collateral task. The major results of the experiments indicated that when multiple cautionary-warning signals are presented peripherally, the use of a master signal reduces response time and the number of signals missed. Results also indicated the following.

- Auditory master signals are superior to visual.
- The use of a combined visual/auditory master produces the fewest missed signals.
- A two-tone auditory master is superior to a one-tone.
- For illuminated legend signals, a dark legend on an illuminated background is superior to an illuminated legend on a dark background.

A master warning has been thought to lower choice reaction time provided it is timed to be exactly 200 ms in front of the specific warning, although at some cost in increased error rate (Cohn, 1995). A substitution for a master caution may be a repetitive flash of outlines in the display.

A master caution is known from avionics and could also be used advantageously in automotive systems. It permits the reduction of the number of isolated displays and controls and guarantees a fast detection because of its central position.

6 Auditory warnings

The multitude of information to be displayed to the driver through new information systems may create the need to minimize visual load and make more and better use of the auditory channel.

Auditory displays

- are excellent at attracting attention,
- are comprehensible to users who do not read, and
- do not require visual processing (Laux, 1993).

Auditory warnings can be distinguished by

- tonal signal, e.g. an intermittent tone (see 6.3),
- auditory icons, e.g. sound of a tyre skidding (see 6.3), and
- speech output, e.g. spoken instruction “Brake !” (see 6.4).

EXAMPLE A sound with increasing frequency for “upwards” is something between “Tonal signal” and “Auditory icons” and is discussed together with “Tonal signal”.

An auditory warning can have three functions (Voss and Bouis, 1979):

- getting attention,
- classification of the hazard type,
- further specification of the situation and/or the needed action.

The standard "ISO 15006, *Road vehicles — Ergonomic aspects of transport information and control systems — Specifications and compliance procedures for in-vehicle auditory presentation*" provides ergonomic specifications for the design and installation of auditory displays presenting speech and tonal information while driving. The aim of this International Standard is to help the designers to provide auditory messages which meet usability, comfort and safety criteria for moving vehicles.

6.1 Psychological/physiological bases

Psychological research proved the existence of several systems within the sensorial memory such as acoustical, visual and tactile. There is a considerable increase in the ability of the human being to divide his attention ("time-sharing") between two inputs when these are in different modalities (Gropher, 1980; Treisman and Davies, 1973). The theories of divided attention and of multiple tasks deal with the manifold interdependencies between the resource components (see Multiple resource theory, Clauses 3 and 4).

Dividing attention is more difficult with the progress of information processing because the "bottleneck" for information processing becomes more and more narrow from perception until response selection and execution (Harris, 1978). Because division of attention is easier when two tasks use different subsystems (Treisman and Davies, 1973), the type of information is an essential parameter regarding time-sharing with different modalities.

If spatial information must be handled simultaneously with verbal information two different subsystems are concerned, one for the spatial and one for the verbal information (see Clause 9). In consequence, time-sharing can be performed easily in tasks, e.g. with spatial information presented visually and verbal information presented in the auditory modality.

If two different sets of verbal information must be handled simultaneously, the degree of information processing must be considered. In the case of peripheral processing levels (e.g. detecting particular syllables) or early verbal processing levels (e.g. detecting terms out of a particular category), there is a better time-sharing performance with different modalities (Rollins and Hendricks, 1980). With further processing, the use of different modalities does not increase performance since vision and hearing share a single semantic system (Treisman and Davies, 1973).

The incoming auditory information is kept for some hundreds of milliseconds or even seconds within an echoic memory. Within this memory,

— pattern recognition,

— coding of information, and

— matching with expectancy

is done (Heller and Krüger, 1996).

If stimulus and stimulus-expectancy correspond exactly, an overlearned or innate reaction pattern is released; then an automatic reaction can be expected (see 3.3). If there is a mismatch between stimulus and expectancy, the (hypothetical) Limited Capacity Control System (LCCS) will be activated. The situation is analysed and the reaction is planned within the working memory. This activity is connected with effort, i.e. a controlled reaction can be expected.

It has been shown in numerous experiments that the human being is able to listen to one of two simultaneous speech sequences while ignoring the other, by selecting items for attention which have some features in common (Deutsch and Deutsch, 1963). It seems that selection of wanted speech can be performed on the basis of highly complex characteristics, i.e. the content of the two messages is analysed prior to the acceptance of one and rejection of the other.

Another mechanism assumes the existence of a shifting reference standard, which takes up the level of the most important arriving signal (Deutsch and Deutsch, 1963). A dominant signal as it arrives is capable of pushing some level up to its own. Any signal which arrives then or after and is of lesser importance will be below this level.

In most countries, persons who are partially or completely deaf retain the right to drive. Consequently, a message concerning the safety of the driver or other people must not be presented exclusively by auditory means. That means, information being critical for safety must also be presented visually (Heller and Krüger, 1996).

Furthermore, older drivers are particularly intolerant of additional audible communication. Overloading the audible communication channels can lead to irritation and stress for them.

When considering the use of auditory signals or speech as warning signals, the specific human processing mechanisms have to be considered. There are different steps coupled with the echoic memory which transform the original signal into a meaningful code, whereby matching with expectancy is a central factor. On the one hand, with auditory presentation there is good chance of making use of the human capability of dividing attention, especially in the driving environment. On the other hand, there are specific pitfalls (annoyance, etc.) which must not be ignored.

6.2 Advantages of auditory presentation

Auditory displays are recommended for emergency situations in particular (Laux, 1993). On the positive side, our sensory system is set up to detect change automatically, so the onset of sound can be very attention-getting, for example, when visual attention is overloaded. People automatically attend to stimuli that are unusual or intense, so the use of unexpected or intense sound signals would attract attention. Some sounds have particular learned associations with danger or hazard and will therefore be attended to because they have high informational value.

Auditory displays have great potential for alerting users to hazards, but their design must be carefully considered. Too many auditory messages or unimportant messages will result in user habituation, and then the users simply will not respond to the signal at all. The onset of sound will no longer be unusual and attention-attracting. Users soon become habituated to any stimulus they hear frequently or which has no informational value to them. It is not unusual to see people driving long distances with their turn signals flashing because they have become habituated to the auditory signal.

To be effective as warnings, auditory messages should be researched to determine which ones are most likely to be heard and attended to by most users. They should be used sparingly. A “talking vehicle” should be avoided (Laux, 1993).

So, auditory presentation is recommended (Galer and Simmonds, 1984):

a) for signals of acoustic origin;

b) because it is omnidirectional (independent of head orientation);

c) because it cannot be involuntarily shut off;

d) since it is a supplement to overloaded vision;

e) it can draw attention to visual indicators;

f) when vision is limited or impossible.

However, in the vehicle environment, auditory presentation cannot be relied on solely because of partial or full deafness of drivers (see above). Therefore, auditory displays can only be redundant to visual (or other) displays (Galer and Simmonds, 1984).

6.3 Tonal signals, auditory icons

Tonal (nonverbal) auditory signals[7] are defined by their acoustic parameters, typically including amplitude, spectral makeup, and temporal characteristics, whereas auditory icons are representational sounds that have specific stereotype meanings defined by the objects or actions that created the sound (Mynatt, 1994). The auditory icons, (e.g. a sound with increasing frequency for "upwards"), are also discussed in this clause.

6.3.1 Advantages of tonal signals

Even though speech output has a number of distinctive advantages (see 6.4.1), there are circumstances in which non-speech auditory signals may be more desirable (Doll and Folds, 1985).

— Certain non-speech signals may have a commonly recognized meaning as a result of long, consistent usage and should therefore be preserved.

— Tonal signals do not disturb human voice communication as much as speech does.

(For a comprehensive comparison of tonal signals and speech output, see 6.5.)

6.3.2 Standards

ISO 7731 defines criteria applicable to the recognition of sound danger signals for signal reception areas, especially in cases where there is a high level of ambient noise. It specifies the safety and ergonomic requirements and the corresponding test methods for auditory danger signals and gives guidelines for the design of the signal to be clearly perceived and differentiated.

6.3.3 Attributes

Tan and Lerner (1995) defined and weighted the key attributes of the auditory warnings in vehicles by expert judgements. The highest weighted attributes are listed in Table 14 (also see Figure 13).

Five groups of attributes were rated significantly different from one another in the rating task:

a) conspicuousness,

b) discriminability,

c) meaning,

d) urgency, and

e) response compatibility.

The top two attributes in the chart, conspicuousness and discriminability, indicate that even a well-designed auditory warning is ineffective, unless it is audible (conspicuousness) within a background noise and is unique (discernible) from other ambient sounds. The remaining three attributes in this group are also among the more critical attributes associated with auditory warnings. Specifically, once attention is drawn to a unique sound, its meaning must then be immediately recognized as being a warning. The perceived urgency of the sound identified as a warning must then be conveyed in order to motivate a rapid response (response compatibility).

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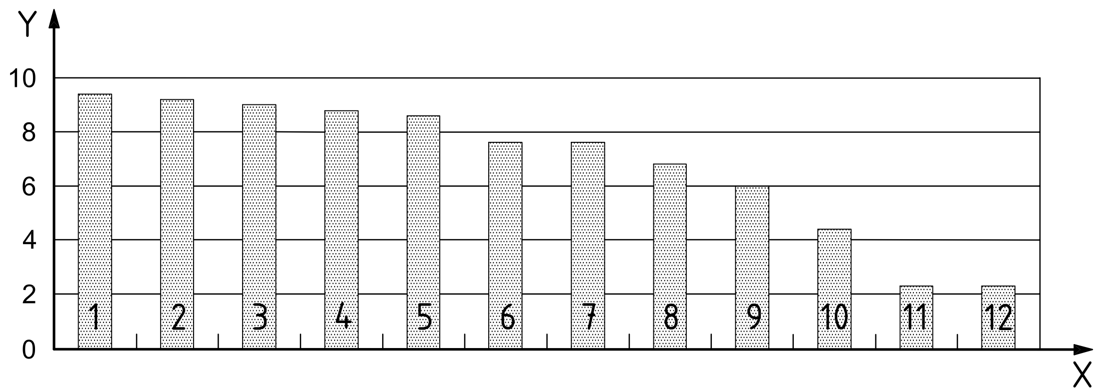
7) The term "earcon" is not used here. Heller and Krüger (1996) use it as substitute for tonal signals and for auditory icons.

Table 14 — Key attributes of the auditory warnings in vehicles (Tan and Lerner, 1995)

Attribute	Definition	Ranking
Conspicuousness	The auditory warning is noticeable within other noises and sounds in the vehicle.	9,4
Discriminability	The auditory warning is uniquely identifiable and distinct from other sounds in the driving environment.	9,2
Meaning	The auditory warning unambiguously conveys or suggests the meaning of, e.g. “imminent crash”.	9,0
Urgency	The auditory warning conveys the proper sense of importance motivating an immediate response.	8,8
Response compatibility	The auditory warning causes the driver to anticipate and prepare for an emergency response.	8,6
Experience compatibility	The auditory warning follows natural and learned relationships of users, such as sirens associated with emergency.	7,6
Startle effect	The auditory warning does not startle or surprise the driver causing a delayed reaction.	7,6
Orienting response	The auditory warning can be easily localized in 3-D sound space, and causes the driver to look in the direction of the hazard.	6,8
Appropriateness	The auditory warning is compatible with the vehicle environment.	5,7
Annoyance	The auditory warning is not annoying or irritating to the driver (assuming minimal false alarm rates).	4,4
Musicality	The auditory warning is melodious.	2,3
Naturalness	The auditory warning does not appear artificial or computer generated.	2,2
Loudness	The sound has high volume and intensity.	—



Key

X attributes of tones
Y rating
1 conspicuity
2 discriminability
3 meaning
4 urgency
5 response compatibility
6 experience compatibility
7 startle effect
8 orienting response
9 appropriateness
10 annoyance
11 musicality
12 naturalness

Figure 13 — Weighed attributes of auditory signals (Tan and Lerner, 1995)

The next group of attributes that were similarly rated includes experience, compatibility and startle effects. Although these three attributes were rated as significantly less important than the first group, they do offer additional insight into the performance of a warning sound. The performance of a warning sound can be influenced by a person's past experience with other warning sounds. For instance, a siren is almost always associated with an emergency situation. The rating of startle effects indicates that a warning should not cause a person to react in an inadvertent or delayed manner due to an initial startle response created by a sound (see 6.3.4.3).

Certain attributes for tonal warning signals are judged to be important, especially conspicuousness, discriminability, meaning, urgency and response compatibility. Disturbing effects like the startling effect and annoyance are less important though they should not be underestimated. This ranking can help to resolve contradictory design objectives.

6.3.4 Sensorial parameters

The following definitions have been made (Heller and Krüger, 1996).

- **Auditory threshold**: The acoustic intensity of a signal which is detected in 50 % of all cases within a defined acoustic environment. The auditory threshold is a function of the frequency composition of the signal as well as of the background acoustic environment.

- **Audibility**: The percentage with which an auditory signal is perceived within a defined acoustical environment. For in-vehicle signals, audibility should be as high as possible (usually 95 %). Audibility is equivalent to the detection rate of the signal.

6.3.4.1 Signal frequency

For tonal signals, the suitable frequency range lies between 500 Hz and 4 000 Hz (Heller and Krüger, 1996). The signal shall contain no significant information outside of this frequency range. An even more restricted range is given by Galer and Simmonds (1984), who recommend frequencies between 500 Hz - 3 000 Hz.

This frequency range conforms more or less with that being specified for military aircraft[8)] in MIL-STD-1472C (Doll and Folds, 1985). Those requirements include the allowed frequency range of 200 Hz - 5 000 Hz.

The recommended frequency range for in-vehicle auditory corresponds relatively well to the recommended frequencies for machinery warnings, i.e. 300 Hz to 3 000 Hz (ISO 7731).

In a noisy environment, signal frequencies as different as possible from the most intense frequencies of the noise should be used (Galer and Simmonds, 1984). In this way the masking of the signal by the noise is minimized. The more the centre frequency of the octave band where the danger signal is the highest differs from the centre frequency of the octave band where the ambient noise is the highest, the easier it is to recognize the danger signal.

Pure tones have to be avoided because standing wave patterns cause resonance and antiresonance areas so that the audibility of a signal at the driver‘s head cannot be guaranteed (Heller and Krüger, 1996). A broad band-sound or a mix of narrow-band sounds, with distinctly separated centre frequencies, is recommended.

Another motivation of using complex tones is that some people experience deafness to specific tones (Galer and Simmonds, 1984). Hearing sensitivity at high frequencies tends to decrease with age, particularly for men. So, high frequencies above 2 000 Hz for warning signals should be avoided if the older population or industrially induced hearing losses is considered.

8) Though aircraft conditions in respect to noise level, communication requirements etc. are quite different to vehicle conditions, they are included here for purposes of comparison.

Patterson (1982) recommends that signals in military aircraft be composed of four or more prominent frequency components in the range from 1 000 Hz to 4 000 Hz, because multicomponent sounds are more difficult to mask. He also speculates that using regularly spaced components, i.e. harmonics, would provide added resistance to masking over sounds with non-harmonic components. The power across the harmonics could be used to indicate the urgency or criticality of the warning (see 6.3.6.1).

Tonal warning signals should have frequencies between about 500 Hz and 3 000 Hz. To take the older population into consideration, the discriminating frequencies should be below 2 000 Hz. The signal frequencies should be as different as possible from the most intense frequencies of the noise in vehicles, and a broadband sound or a mix of narrow-band sounds is recommended.

6.3.4.2 Signal Level

The selection of optimal sound amplitude is a matter of balancing listener comfort against message audibility (Heller and Krüger, 1996). The latter is primarily a function of signal-to-noise ratio (SNR). Therefore, three different "usable auditory areas" are defined, corresponding to different combinations of sound amplitude (expressed in L_{eq}/1 s, CIE 804, 1985-1989) and signal-to-noise ratio (see Table 15). Each area is associated with different levels of message intelligibility, user comfort and acceptance, and auditory impairment.

Table 15 — Usable auditory areas and corresponding sound amplitudes and signal-to-noise ratios

Auditory areas	Loudness L_{eq} /1 s[a]	Signal-to-noise ratio L_{eq} /1 s[a]	Type of information[b]
Limit area	< 50 dB	< 5 dB	Reassurance message, announcement of new message on visual channel
Comfort area	50 dB to 70 dB	5 dB to 10 dB	Speech messages: — guidance; — traffic messages; — announcement of fog and ice.
Emergency area	70 dB to 90 dB	10 dB to 15 dB	Urgent warnings: — risky closing speed; — unsafe following distance.
Health impairment area[c]	> 90 dB	> 15 dB	Not recommended

[a] Values are A-weighted. "L_{eq}" is the equivalent sound level.

[b] There is no general agreement as to what "type of information" a message belongs to. Is "unsafe following distance" an "informing message" or an "urgent warning"? Obviously, this classification depends an the driving situation and evaluation by the driver. Up to now, technical systems have not been able to detect and evaluate driving situations with 100 % reliability.

[c] Health impairment area" is introduced by the reporter.

— **Limit area**: This area is under 50 dB (A-weighted) (L_{eq}) and under 5 dB (A-weighted) (SNR). This area is considered comfortable by most drivers. While the intelligibility probability may not be very high, this area may be used to present tone signals for reassurance, or repeated signals when some of them can be missed without any serious consequences. The annoyance level is low, but the attentional demand (effort for listening to) may be incompatible with difficult driving tasks.

— **Comfort area**: This area lies above 50 dB (A-weighted) (L_{eq}) and between + 5 dB (A-weighted) (SNR) and + 10 dB (A-weighted) (SNR). This area is ideally suited for comfortable and pleasant vocal interactions. The intelligibility index is high (about 95 %), but some errors may occur. This area must be dedicated to the messages which can be repeated.

— **Emergency area**: This area lies above 70 dB (A-weighted) (L_{eq}) and between + 10 dB (A-weighted) and + 15 dB (A-weighted) (SNR). Detectability and intelligibility are very good, but a long acoustical exposure in this area may be annoying or tiring. This area must be used for urgent but rare signals, in conformity with existing standards regarding the emergency signals (EN 894-2:1992).

  This SNR range for the emergency area within vehicles corresponds to the "clear audibility" definition in ISO 7731, concerning machinery safety (ISO 7731, see Bibliography): a signal sound is clearly audible when the A-weighted sound level of the signal exceeds the level of ambient noise by 15 dB or more.

  More accurate predictions for a clear audibility can be obtained by the use of octave band analysis or 1/3 octave band analysis (ISO 7731). When using octave band analysis, the sound level shall exceed the masked threshold by at least 10 dB in one octave band or more in the frequency range of 300 Hz to 3 000 Hz. The A-weighted sound level of the signal however shall be not less than 65 dB to ensure its audibility amongst recipients with mild hearing loss. If the frequency and/or the temporal distribution of the auditory danger signal clearly differ from the corresponding characteristics of the ambient noise, a lower sound pressure level of the signal may be sufficient.

  The SNR range for the emergency area does not perfectly conform to the recommendations in military aircraft. MIL-STD-1472C specifies a minimum SNR of 20 dB for military aircraft (Doll and Folds, 1985). Signals above their masked threshold are difficult to miss (Patterson and Milroy, 1979). A loud signal (still below pain) is perceived as annoying by the pilot. So, Patterson (1982) recommended a minimum level of 15 dB above the predicted masked threshold to insure detectability and a maximum level of 25 dB to guard against annoyance and disruption of thought and communication.

— **Health impairment area**: Messages with a sound amplitude higher than 90 dB(A) should be avoided because of the high risk of annoyance and auditory impairment. Exposure to noise at this level may produce a temporary threshold shift and, if repeated, definitive traumatic deafness.

Because of the individual differences in the hearing capabilities of the drivers and the large variation in background noise, it would be desirable that the signal level be manually adjustable or automatically adaptive to the frequency spectrum of the background noise (Heller and Krüger, 1996). As a first step, it is recommended that the driver can easily modulate the signal level within a range of ± 10 dB(A) around the target area. Especially for speech signals, a frequency-specific amplification should be provided which allows the driver to adapt the signal to his/her hearing capabilities.

According to Woodson and Conover (1981), onset rates of > 1 dB/ms but < 10 dB/ms are recommended. The offset rate should be equal to the onset rate (NHTSA, 1996).

The selection of an optimal sound amplitude is a matter of balancing listener comfort against message audibility. Three different "usable auditory areas" are defined: limit area, comfort area, emergency area, differing in sound amplitude and signal-to-noise ratio. For warning signals which have to be reacted upon immediately, the emergency area with L_{eq} = 70 dB (A-weighted) to 90 dB (A-weighted) and SNR = 10 dB (A-weighted) to 15 dB (A-weighted) is recommended.

6.3.4.3 Startling effect

The first function of an auditory warning is getting the attention of the user (see the beginning of Clause 6, Voss and Bouis, 1979). This can include a startling effect. A warning should not cause a person to react in an inadvertent or delayed manner due to an initial startle response created by a sound. In particular, the sound should not be too loud or have too short an onset time, which can cause the sound to be perceived as being presented instantaneously. Reactions due to fright may be expected whenever there is an unexpected steep increase in the sound level (e.g. more than 30 dB in 0,5 s, ISO 7731).

The startling effect can be discussed in following context (Heller and Krüger, 1996): the intensity of a reaction is dependent on a matching between

— pattern of stimulus (visual, acoustical) and

— patterns stored in the long-term memory.

Every mismatch results in a reaction which is dependent on the intensity of the stimulus:

— for mild stimuli: Orienting Reaction (OR), after 200 ms to 250 ms;

— for intense stimuli: Defensive Reaction (DR);

— for extreme stimuli: Startle Reflex (SR).

The orienting reaction (OR) is sensitive to new stimuli and can be habituated. By intensifying the stimulus, the OR will change into a DR and then into a SR.

Voss and Bouis (1979) compared the following different signals to simulate oil-pressure failure in a field experiment to investigate the startling-reflex:

a) permanent tone with a sudden onset;

b) permanent tone with soft onset (linear envelope);

c) blinking lamp;

d) intermittent tone and blinking lamp.

The tone according to a) resulted in the shortest reaction times (see Figure 14), i.e. it showed a very high “request character”. Some startling reflex with full braking occurred only with a). The driving errors were relatively high (23 %). The other variants also led to relatively short reaction times, without startling reflex. With variant b), the signal was detected rather early but led later to a specific reaction. Good compromises between high attention value and low startling reflex are therefore the signal variants c) and d).

There is no sharp limit between attention-getting and the startling effect (Voss and Bouis, 1979). The same stimulus can induce different reactions in humans. Moreover, the startling effect of a stimulus decreases when it is repeatedly presented. Lerner *et al.* (1996) recommend onset rates for crash-avoidance sounds $>$ 1 dB/ms but $<$ 10 dB/ms for being rapid enough to alert the driver, but not so rapid as to induce severe startle effects.

There is a tightrope walk between alerting and annoying by auditory signals. The more conspicuous an auditory signal is, the more it draws the listener’s attention, but the greater is the risk of it being disturbing. A compromise is a soft onset of the signal, being still moderate in loudness. The stimulus should be between mild and intense, while avoiding a startling effect. A way should be found of keeping up the correct expectation of warning signals, e.g. by including them in the check of a starting vehicle.

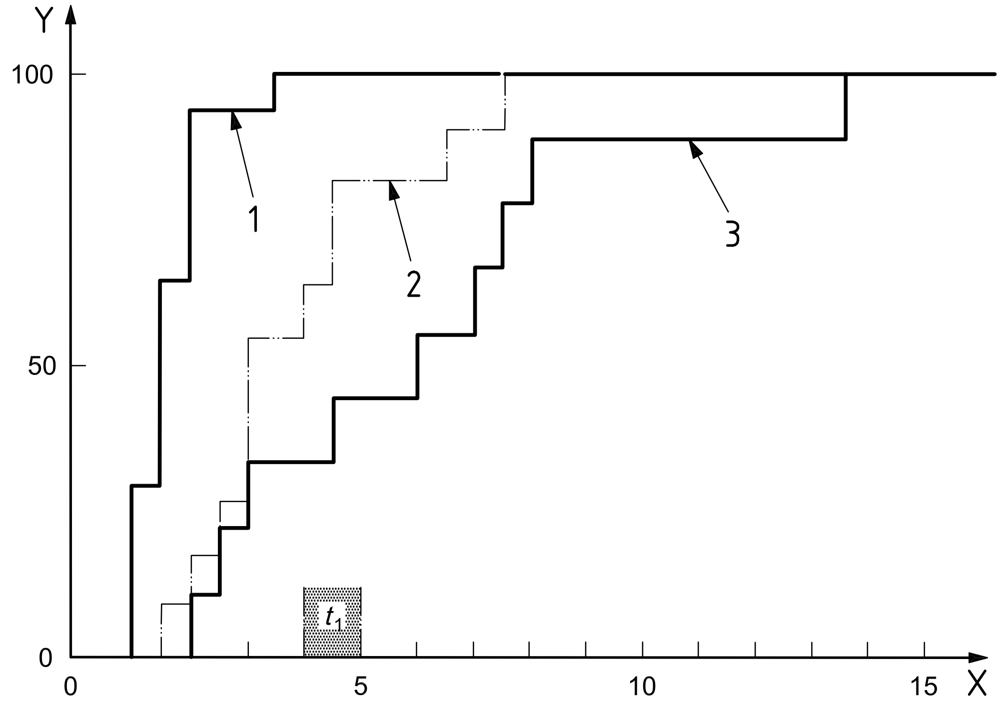
6.3.5 Coding parameters

6.3.5.1 Intelligibility

Each signal is intended to give rise to a driver’s behaviour (perceptive, cognitive or motor) (Heller and Krüger, 1996). This intended behaviour has to be explicitly formulated by the designer of the signal. It has to be proven whether the perceived acoustic signal is able to induce the intended cognition or behaviour (= intelligibility).

EXAMPLE 1 After hearing a special sound, the driver must recognize that he/she has to look at a visual display within 5 s.

EXAMPLE 2 After hearing a special sound, the driver must recognize that he/she should brake immediately (within the next second).



Key

X reaction time, t, in seconds

Y cumulative frequency, in percent

1 permanent tone with sudden onset

2 blinking lamp

3 intermittent tone (soft onset) and blinking lamp

Figure 14 — Cumulative frequency of the reaction times with binary alarms (Voss and Bouis, 1979)

A measurement procedure to define intelligibility and a suitable criterion for the degree of the required intelligibility should be proposed (Heller and Krüger, 1996). It should be discussed whether this measure should refer to psycho-acoustical parameters of speech perception (evaluating physical characteristics of the speech signal against physical characteristics of the background noise) or whether the measure should be based on psychological procedures (parameters of correct understanding, of correct behaviour).

It should be kept in mind that tonal signals must be learned by drivers (association between signal and message), especially in the case of rarely-displayed tonal signals, when regular exposure may be necessary to clarify and reinforce their meaning. A tonal signal which is not understood by the driver can cause inappropriate reactions. If a corresponding visual cue exists, both should be displayed at the same time.

In addition, the number of tonal signals used in a vehicle should be limited with respect to intelligibility and discriminability (see 6.3.6.1).

The meaning of the auditory danger signal should be unambiguous (ISO 7731). Auditory danger signals and signals serving other purposes should not be similar.

6.3.5.2 Types of tonal signals

The following tonal warnings can be distinguished (Galer and Simmonds, 1984) (see Table 16).

Table 16 — Tonal warnings (Galer and Simmonds, 1984)

Alarm	Intensity	Frequency	Attention-getting ability	Noise-penetration ability	Special features
Horn	High	Low to high	Good	Good	Can be designed to beam sound directionally
Siren	High	Low to high	Very good if pitch rising and falling	Very good with rising and falling frequency	Can be coupled to horn for directional transmission
Bell	Medium	Medium to high	Good	Good in low frequency noise	Can be provided with manual shut-off to insure alarm until action is taken
Buzzer	Low to medium	Low to medium	Good	Fair if spectrum is suited to back-ground noise	Can be provided with manual shut-off to ensure alarm until action is taken
Chime and gong	Low to medium	Low to medium	Fair	Fair if spectrum is suited to back-ground noise	—
Oscillator	Low to high	Medium to high	Good if intermittent	Good if frequency is properly chosen	Can be presented over intercom system

Stanford *et al.* (1988) proposed another somewhat radical method of alarm design in which vowel sounds figure centrally. Their studies show that these types of sound are at least more aesthetically acceptable than many currently in use.

The recommendations of DIN 11429 start from message urgency and comes to a more crude classification for in-vehicle information signals (see Table 17).

Table 17 — Recommendations of DIN 11429

Message urgency	Sound signal	Corresponding light signal
Announcing	Two-times chimes, high-low non recurrent (followed by instruction or message)	—
Caution; act when necessary	Pattern of segments with constant pitch, the shortest at least 0,3 s	Yellow
Danger; urgent action required	Sweeping sounds, burst of sounds, alternating tone pitch, fast rhythm or dissonance	Red

A tonal signal has two functions: attracting attention and providing information (Heller and Krüger, 1996). This information is usually very specific. However, tonal signals may also be selected to provide information of a general nature, such as “watch out” or “danger”.

EXAMPLE 1: Specific: Announcement of a new message on a visual display.

EXAMPLE 2: General: “The driving situation has become dangerous, be cautious.”

Tan and Lerner (1995) investigated acceptable candidate sounds[9)] for use as imminent crash-avoidance warnings in vehicles. The study addressed the important attributes of such warnings, then measured those attributes among a collection of possible alternatives. Thirty-two participants of two age groups listened to 28 warning stimuli under two levels of simulated vehicle noise [sedan: 72 dB (A-weighted), truck: 78 dB (A-weighted)] and rated each sound on 11 attributes (conspicuity, discriminability, startle effect, etc.; see 6.3.3). The 28 sounds consisted of 16 auditory tones and 12 speech outputs (see 6.4.2.1). The auditory tones were very varied in frequency and temporal characteristics.

The subjects preferred the following stimuli:

a) low-fuel aircraft warning,

b) radio shack, and

c) repetitive acoustic patterns

that consisted of four pulses. The majority of these stimuli had frequency spectra that showed relatively high frequency energy, and exhibited multiple harmonious peaks above a fundamental basic tonal component. They all had multiple bursts or pulses in their time histories, which gave them time-varying or intermittent character. The following sounds were not among the preferred ones: vehicle horn, tyre skid, continuous tones, etc.

There are a number of tonal alarm sounds like the horn, bell, buzzer, etc., all of which possess specific characteristics with respect to attention-getting and noise-penetration ability. They include different urgency cues from announcing to caution and danger. Warning tones should have at least some sort of time-varying or intermittent character.

6.3.5.3 Temporal characteristics

The distinctiveness of non-speech signals could be enhanced by varying the temporal characteristics over a wide range and by using complex tones with multiple harmonics (see 6.3.5.1). Patterson (1982) showed that alarms, which are spectrally quite different from one another, were nevertheless confused because when the on/off cycle was repeated at the same rate (see below). Edworthy and Meredith (1994) demonstrated that warnings which do not share the same repetition rate, but merely share the same proportion of on/off time, are also confused.

A pulse is a sound contained within one amplitude envelope, which has an onset, an offset, and a specific duration. A pulse can be repeated several times with intervals of silence between each pulse. The resultant unit is referred to as a burst of sound. The burst forms the basis of a complete warning sound.

Haas (1992) investigated the effect of pulse format, pulse duration, and time between pulses on the perceived urgency of warning signals. The intention was to determine the best combination of variables and levels of variables in relation to the perceived urgency of the warning signals. Five pulse formats were used; all formats had a frequency range of 500 Hz to 3 000 Hz. The simultaneous pulse format consisted of four pure tone components at 500 Hz, 1 000 Hz, 2 000 Hz and 3 000 Hz, being presented concurrently during one pulse duration. The sequential pulse format consisted of the same components presented sequentially (rising/falling/rising and falling). The times between pulses were 0,0 ms, 150 ms and 300 ms. The pulse duration was 200 ms, 350 ms and 500 ms.

The results of Haas (1992) indicated that only pulse format and time between pulses were significant. Subjects rated sequential pulses as being less urgent than any other format. Signals with shorter inter-pulse intervals were rated as significantly more urgent. Signals with a between-signal duration of 150 ms had significantly higher urgency ratings than signals with between-pulse duration of 300 ms.

9) The study evaluated both (non-verbal) tonal signals and spoken voice warnings. The results of the latter are presented in Clause 6.4.

For auditory alarms in vehicles, Galer and Simmonds (1984) generally recommend the use of a modulated signal, such as an intermittent beep repeated at rates of 1 to 8 beeps per second or warbling sounds that rise and fall in pitch. The signal type (pulsating or warble tone) corresponds to the recommendation for machinery safety. But the quantitative recommendations overlap only partly, i.e. a pulse repetition frequency for machinery safety in the range of 0,2 Hz to 5 Hz (ISO 7731).

Signals with a between-pulse interval of 0,0 ms (no interval) had significantly higher urgency ratings than those with between-signal intervals of 150 ms and 300 ms. According to Edworthy and Meredith (1994), however, a continuous tone is bad as an attention-getting device, because our perceptual system is geared towards change. Furthermore, it is bad from a cognitive point of view, because absolute pitches are badly recognized by the human being [10].

To reduce the annoying and disruptive effects of auditory signals, Patterson (1982) recommended using

— intermittent warnings with a high off-time relative to on-time and

— a gradual signal onset (see 6.3.4.3).

One of the most important characteristics of tonal signals are the temporal attributes. They serve as attention-getting devices, as a discriminability factor and as urgency cues. Intermittent beeps repeated at rates of 1 to 8 beeps per second or warbling sounds are recommended for warning alarms in vehicles. Pulse format and time between pulses influence the perceived urgency significantly.

6.3.5.4 Spatial characteristics

A new type of interface, the three-dimensional (3D) audio display (auditory head-up display, AHUD) is being developed to enhance cockpit displays in military aircraft (King and Oldfield, 1997; Sorkin *et al.*, 1989). This system would provide data about signals or events occurring at different spatial locations relative to the aircraft. A key property of this system is the ability to display target azimuths and elevations that are fixed relative to the heading and attitude of the aircraft and independent of the position of the pilot‘s head. Auditory 3D displays take advantage of the strengths of the auditory system: the human auditory system can detect and localize sounds from any direction around the listener without any movement of the sensory apparatus (Rudmann and Strybel, 1999). Furthermore, auditory events are localized in reference to the position of the listener.

An experiment tested the ability of observers to localize targets with an AHUD under different movement conditions (Sorkin *et al.*, 1989). Three different conditions relating the observer‘s head movement to the target‘s spatial position were tested:

a) target fixed in physical space (normal AHUD mode),

b) no head movement allowed, and

c) target fixed in position relative to the observer‘s head.

Azimuthal localization was much better in mode a), demonstrating the contribution of visual, kinaesthetic, and vestibular cues to sound localization. The auditory cues generated self-movements of the observer’s head which provided significant additional information for localizing acoustic targets.

Wallace and Fisher (1997) examined the design of an auditory interface for a vehicle collision-avoidance warning system with spatial cues. Six loudspeakers were equally spaced around a subject in an anechoic chamber. The number and balance of relative probabilities were altered. The subjects had to indicate the location of the speaker from which the tone, a single broadband noise signal low-pass filtered at 8 500 Hz,

10) If, nevertheless, a single sound is used, Lerner *et al.* (1996) recommend a warning duration between 200 ms and 500 ms to avoid signal missing. The shorter the duration of the tone is, the greater its intensity needs to be.

was presented. The speakers located in front and behind a subject had no effect on the response times, if they were positioned asymmetrically with respect to one another. However, if the speakers were located symmetrically, the response times were lengthened significantly. The front-to-back symmetry and not the specific axis of that symmetry was the key factor.

Broadband signals encompassing frequencies from 0 kHz to at least 13 kHz are required in order for the listener to accurately localize signals (King and Oldfield, 1997). The four participants in the authors experiment localized broadband signals quite accurately (within an uncertainty range of 10°) when they were presented in front of the head. Localization error was slightly greater when the signals were presented behind the head.

Rudmann and Strybel (1999) examined auditory spatial facilitation of visual search performance. The auditory cue either spatially coincided with the (visual) target or was displaced from it. Distracters were manipulated globally and locally with different densities. Coincident auditory cues minimized local and global distracter effects, suggesting that auditory spatial cues facilitate both target localization and identification. Participants were unable to ignore inaccurate auditory stimuli.

With oncoming collision warning systems in vehicles, spatially-coded auditory signals are becoming important. Human beings are capable of differentiating different directions of sounds if the signal is designed adequately and speakers are located carefully. The detection and localization of vehicles to the side of the subject vehicle can be assisted by broadband auditory 3D displays, analogous to the spatial location of a dangerous threat in military aircraft. Auditory signals can facilitate reading of visual displays if they are close together.

6.3.5.5 Auditory icons

Auditory warnings can be categorized as either intentional or incidental. Intentional warnings are sounds specifically designed to warn.

EXAMPLE 1 Sirens, horns, simple and complex tones, and speech warnings are all examples of intentional warnings.

Incidental warnings (auditory icons), on the other hand, are sounds inherent to a system that are sometimes caused by changes in the system and which warn of an event that has just occurred, an impending event, or a potentially dangerous situation.

EXAMPLE 2 Examples of incidental warnings include the hissing noise generated by air escaping a punctured tyre or the screeching of worn brakes.

The use of auditory icons as intentional warnings may be useful in depicting incidental warnings well in advance of a critical situation. While traditional non-verbal auditory displays are defined by their acoustic parameters, auditory icons are representational sounds that have specific stereotype meanings defined by the objects or actions that created the sound (Mynatt, 1994), e.g. the sound of breaking glass or tyres skidding. The identification of auditory icons requires “everyday listening”, which is the experience of listening to determine the source itself (Gaver, 1994).

Auditory icons can be classified, identified and categorized more efficiently than non-representational sounds (Belz *et al.*, 1997). This implies that if auditory icons are used as warning signals, the time required to learn and use the system would decrease while an operator‘s accuracy and response time would improve.

The number of auditory icons capable of being understood and remembered has been found to exceed the established limits of six to eight distinctly different sounds for traditional auditory warnings (Gaver *et al.*, 1991).

Belz *et al.* (1997) investigated the perceived meaning and perceived urgency of auditory icons (see Table 18). Some auditory icons within a group of auditory icons with the same or similar meanings elicit a greater (or lesser) response in terms of their perceived urgency. In the meaning group “Low oil”, none of the proposed auditory icons suitably represented the task.

Table 18 — Meaning groups and auditory icons

Meaning group	Auditory icons
Low fuel	Gurgling, drain clearing
Loss of air pressure	Bottle rocket, air leak, air spurt
High engine temperature	Teapot whistling, boiling water, wildfire
Low oil	Gears grinding, grinding & squeaking, metal crushing, chain rumble
Poor weather	Rainfall, thunder, rain with thunder roll, rain with thunder clap
Train crossing ahead	Short honk, tyre skid, tyre screech, tyre screech & crash
Etc.	

Graham *et al.* (1995) conducted an experiment to compare the effects of conventional auditory collision warnings with auditory icon warnings in terms of reaction times and driver preferences. Drivers were seated in an experimental vehicle while a video of a road scene, interspersed with imminent collisions, was projected ahead of them. The drivers were required to carry out a tracking task on a dashboard screen, decide whether or not a collision was imminent, and hit the brake pedal accordingly. Four types of warning were tested: two traditional warnings (a simple tone and a voice articulating “ahead”) and two auditory icons (the sounds of a car horn and of skidding tyres).

Auditory icon warnings were found to produce significantly faster reaction times than traditional warnings, but suffered from an increase in inappropriate behaviours (reacting with a brake press to a non-collision situation, see below). The auditory icons (horn, tyre-skid) produced faster reactions than the traditional warnings (speech, tone), even though this difference was only in the order of 0,1 s.

One explanation is that the icons differed from the traditional warnings in terms of their urgency. Differently pitched sounds may have been masked to a different extent by the simulated low, rumbling engine noise. Speech warnings in general may require additional time to process and comprehend and therefore result in slower reaction times.

The other small difference noted in the interaction between warning type and location was in the auditory icon warnings. In “stationary vehicle ahead” situations, the horn warning produced faster reaction times than the tyre-skid warning. In pullout situations, this trend was reversed, with the tyre-skid producing faster performance than the horn. The tyre-skid warning is more closely related to the event of a car dangerously pulling out from a side road, whereas for a stationary vehicle ahead, a horn warning may be more closely linked to the driver‘s mental model of events.

It was observed that the more urgent auditory icon sounds (horn, tyre-skid) gave more false positives than the traditional warnings (speech, tone). So there seems to be a less carefully considered reaction to these urgent warnings. A shift in drivers’ criteria to greater reaction speed at the expense of increased false positives may actually be desirable. That is, there may be a greater chance of drivers braking successfully in real collision situations.

Across the collision situations investigated, a car horn sound was considered to be more appropriate than a standard tone. The other tested icon, the tyre-skid, was not rated so highly, but may have suffered from poor quality and realism.

There are auditory signals that include aspects of auditory icons, i.e. a stereotypical association of the signal with a specific meaning. If auditory signals are used for indicating a direction, some human stereotypes can be used (Johannsen, 2000):

— for “upwards”, a melody in higher tones;

— for “downwards”, a melody in deeper tones.

For the sideways direction, different rhythms can be used. Sounds for different states can be supposed. Using this coding method for controlling a robot, the best subjects are able to navigate the robot through a two-dimensional scene with none or very few errors.

Auditory icons have been demonstrated to be superior to conventional signals with respect to recognition and reaction performance in specific scenarios. Auditory icons as intentional warnings may be useful in depicting incidental warnings well in advance of a critical situation. Considerably more than six items (as in traditional tones) can be distinguished, understood and remembered. Specific auditory icons are associated with specific driving situations. Urgent auditory icon sounds, like a tyre-skid, result in more false reactions than the traditional warnings.

Concluding Subclauses 6.3.5.1 through 6.3.5.4, the different coding types can be exemplified for crash-avoidance warnings by referring to Lerner *et al.* (1996). They recommend that imminent crash-avoidance warnings should convey more urgency than cautionary crash-avoidance warnings through the following characteristics (see Table 19).

Table 19 — Urgent warnings and cautionary warnings (Lerner *et al.*, 1996)

Urgent warnings	Cautionary warnings
High signal (or pattern) repetition rate	Low signal (or pattern) repetition rate
High intensity	Low intensity
High fundamental frequency	Low fundamental frequency
Large frequency oscillations within auditory patterns	Small frequency oscillations within auditory patterns

Continuously-repeating auditory patterns may be used for acoustic crash-avoidance warning displays as long as they are short of duration or cycle time. Such patterns should be easily learned and perceived and be absolutely identifiable by the driver (NHTSA, 1996).

6.3.6 Organizational parameters

Because simultaneous messages can be difficult to understand, auditory inputs should be presented serially, and they should be adjustable in terms of volume, equalization and type (and possibly speaker‘s voice) (Wierwille, 1993). This means that all in-vehicle auditory displays must be connected together in such a way that messages are co-ordinated on the basis of priority. In military aircraft, the effect of multiple concurrent caution/warning systems on aircrews performance is also a major concern (Doll and Folds, 1985).

6.3.6.1 Discriminability, number of signals

It is important to make sure that there is no confusion among the various signals in the vehicle's auditory repertoire (Heller and Krüger, 1996). When a new auditory signal is proposed or introduced, it is necessary to verify that it will not be confused with existing signals, particularly if this signal is an emergency warning.

The number of tonal signals used in a vehicle should be limited with respect to intelligibility and discriminability. For military aircraft, a maximum of four signals is prescribed when absolute discrimination is required (MIL-STD-1472C). A military aircraft which violates this principle is the F-15, which uses 11 different non-speech signals, thus reducing the chances that the crew will remember the meaning of any given signal (Doll and Folds, 1985).

Human beings can, however, effectively identify a fairly large number of different sounds, if the sounds vary on multiple dimensions (Doll and Folds, 1985). The question is whether the pilot can remember the meaning of each sound. One week after learning 10 auditory warnings, most subjects correctly recognized 8 or 9 of the signals (Patterson and Milroy, 1979). The most likely source of confusion was temporal similarity (repetition rate and on/off ratio), even though large spectral differences were involved.

ISO 7731 recommends the use of at least two of the acoustic parameters (sound level, temporal distribution, combination of frequencies) to ensure discriminability. The discriminability of non-speech signals could be enhanced, for example, by varying the temporal characteristics over a wide range and using complex tones with multiple harmonics (see 6.3.5.3, Patterson, 1982). Other alternatives are to substitute speech for non-speech signals (see 6.3.6.2) or to back up non-speech auditory signals with visual indicators that provide further information.

Tonal signals for warnings which need different or even opposite actions must be quite different. An example demonstrating violation of this principle is the F-16 aircraft, in which an 800 Hz tone indicates two different failures, which require increasing or decreasing pitch of the aircraft (Doll and Folds, 1985). The confusion between these signals can have disastrous consequences.

A single sound or tone used as a crash-avoidance warning signal should be between 200 ms and 500 ms in duration. If complex tones are used, duration of about 200 ms to 300 ms are recommended (NHTSA, 1996).

Tonal signals have to be clearly discriminated. One aspect is the number of tones, which should be restricted to about four when absolute discrimination is required and the strict prescription for military aircraft is adopted. If multiple dimensions (sound level, temporal distribution, etc.) are used and the signal is combined with text or speech, then considerably more sounds can be used.

6.3.6.2 Prioritization

The concept of urgency is a central one in the developing of new alarm sounds (Edworthy and Meredith, 1994, see 6.3.5.3). It is necessary to attach an appropriate sense of urgency to alarms. Many dimensions of an alarm, such as speed and repetition rate, pitch, harmonic quality, melodic pattern, etc. can affect the perceived urgency of the alarm (Edworthy and Meredith, 1994). Many current applications could produce more levels of urgency by using a greater number of dimensions.

The differentiation between urgency levels appears to be based primarily on the temporal features, particularly the length of the warning signal (see 6.3.5.3). Schreiber and Schreiber (1989) used a continuously repeating sound pattern for top priority situations, an intermittent repeating sound for second priority situations, and a single short one for third priority (compare the time categories of Heller and Krüger (1996): immediate, short-term, long-term, see 6.3.5.4).

The power across the harmonics could also be used to indicate the urgency or criticality of the warning (Doll and Folds, 1985, see 6.3.4.1).

It was revealed that sound pressure level, tone frequency and intermittence of tones provide the perceived criticality and urgency (Uno *et al.*, 1997, 1999). Hence, subjective impressions are increased by greater sound pressure level, higher frequency of fundamental tone, shorter intermittent cycle and higher intermittent rate of tones. Appropriate physical properties should be assigned for the contents of warning.

Including the aspect of urgency in an alarm design and preventing startling effects at the same time is achieved by a somewhat more musical approach to alarm design, e.g. in intensive care units (Edworthy and Meredith, 1994; see 11.2) [11].

Prioritization with respect to urgency is a major concern when designing warning sounds. Many dimensions of an alarm (speed, repetition rate, pitch, etc.) can affect the perceived urgency of the alarm. The time characteristics seem to be the most effective ones.

6.4 Speech output

One way to reduce the visual load of driving and performing in-vehicle tasks is to rely more heavily on auditory output. The technology is now at hand to provide high-quality synthesized or digitally recorded human speech.

11) This “musical approach” was not further specified by the authors.

Speech perception and production is a uniquely human skill, and is highly developed (Edworthy and Adams, 1996). Spoken warnings could be one of the most effective of all warning types. They add an extra dimension to both written and non-verbal auditory warnings. In warnings presented visually with text, they add the paralinguistic elements, and in the case of non-verbal warnings, they add the linguistic element. There are, however, problems of intelligibility and detectability when spoken messages are used in environments where other speech communication is used, and there are additional issues associated with cross-modal warnings.

When we are listening to speech, we take heed of both linguistic and paralinguistic elements, which may be either matched or mismatched and inappropriate. Urgency mapping might therefore be of some consequence in the development of speech warnings.

Speech coding should be used if there is enough time to listen to the full message and to choose a correct action (Heller and Krüger, 1996). It should be selected when it is necessary to provide precise information.

EXAMPLE 1: “Turn right.”

EXAMPLE 2: “Take exit 24.”

6.4.1 Advantages of speech output

Bertone (1982) notes that, unlike simple auditory tones, speech warnings are able to convey information about the nature of a problem, in addition to warning the user of its occurrence. Also, the fact that speech is perceived through automatic, low-level cognitive processes means that speech warnings are more likely to be effective in stressful conditions than coded auditory tones whose meanings have not been learned to the same extent. On the other hand, the meaning of a voice message may not be understood until the message is nearly completed. Given the importance of keeping collision warnings short, a trade-off exists between reduction in the length of message presentation and reduction of processing load.

According to the psychological research several conclusions can be drawn concerning applications of voice output with a certain amount of task loading.

Speech output should be used in the following tasks (Mutschler, 1982):

- time-sharing tasks where rather low or different stages of information processing are addressed;
- tasks involving verbal information, such as the names of any devices;
- tasks involving information that is already in an acoustical form;
- tasks involving the presentation of information which has a high priority, e.g. pointing out a fall in oil pressure [Simpson and Williams (1980) have reported voice warning systems in this context];
- tasks involving information to be memorized for several seconds.

A major difficulty associated with the use of voice output is its conflict with human speech communication. Both are using the aural/oral channel and both are converging, to some degree, onto the unique semantic processing system. To reduce this conflict, one should use different physical features for human-machine and human-human communication.

6.4.2 Sensorial-related parameters

6.4.2.1 Voice, loudness

Spoken messages can be entirely synthesized or they can be constructed from real human speech. The voice characteristics of speech displays should be such that the messages can be easily differentiated from other speech in the vehicle (e.g. passengers talking or speech on the radio). The most obvious way to differentiate automatic speech from natural speech is to make it sound clearly non-human (Brown, Bertone and Obermeyer, 1986).

In a telephone application for American Express, Gardner-Bonneau (1989) found, that the more rigid and mechanical a voice sounded, the more commanding it appeared to be and the more compliant listeners were with respect to instructions presented in synthetic speech. It is also true, however, that listeners may reject synthetic speech if it sounds too robotic and stilted. Drivers are becoming accustomed to much improved voice representations in systems such as route guidance. Thus the voice can sound natural, particularly if preceded by an announcing tone (Stevens, 2002).

According to the standard for military aircraft MIL-STD-1472C, the voice of verbal warnings shall be (Doll and Folds, 1985)

— distinctive,

— mature, and

— presented in a formal, impersonal manner.

Early military warning systems used a female voice to provide contrast with the normal parade of male voices heard in radio/intercom communications. The increasing presence of females both in aircrews and in air traffic control stations could reduce the advantage of using a female voice (Doll and Folds, 1985).

Tan and Lerner (1995) investigated 28 acceptable candidate sounds for use as imminent crash-avoidance warnings in vehicles (see 6.3.5.1). Among them there were 12 speech outputs: “Danger”, “Warning”, “Hazard” in male and female voice, digitized and synthesized. The voice warning words were presented at approx. 156 words/min, and were repeated after about 125 ms. As a class, the voice sounds were somewhat less effective than the acoustic (non-voice) sounds. Within the voice sounds, the digitized voices were rated considerably louder than the synthesized voices. There is, however, no strong basis for excluding any of the four voices, although the female synthesized voice may be the weakest of these choices, unless presented at substantially higher sound levels than other voice stimuli. This stimulus tended to suffer a loss of conspicuity.

Synthesized messages in particular demonstrate some intelligibility problems, although these problems are being reduced as speech systems improve in their sophistication. If voice signals are required for a noisy environment and normal quiet speech is amplified, then if the consonants are adjusted to an appropriate loudness level, the vowels will be too loud. If the vowels are set at an appropriate level, the consonants may not be heard.

Cowley and Jones (1992) compared synthesized and digitized speech, providing a checklist which can be used to help make the decision as to whether a digitized or a synthesized voice message is likely to be the more suitable mode for any particular application. Their comparison is shown in Table 20. If the setting is noisy, then Cowley and Jones recommend the use of synthesized rather than digitized speech. This is mostly because it is easier to match a wholly artificial acoustic signal to a complex noise spectrum than it is to boost acoustic signals which come from a human speaker. The use of digitized, rather than synthesized speech, is recommended if the operator is carrying out some other arduous task at the same time. The main reason for this is that the processing of synthesized speech seems to impose greater demands on cognitive processes than natural speech does. However, this finding may be dated. Since the time of that study, technological advances in synthesized speech have improved intelligibility.

Cowley and Jones (1992) recommend a digitized voice if prosody is important, but the authors also suggest that a synthesized voice may be better if the message is intended as a warning. The implication is that a warning message does not need prosody to be effective — the disembodied, attention-getting qualities of synthesized speech may make it more appropriate for use in warnings.

Intelligibility and recognizability are essential components of any artificial speech production system. There are many source documents to assist the designer in maximizing intelligibility. Intelligibility of a warning, however, does not guarantee compliance.

Table 20 — Comparison of digitized and synthesized speech (Cowley and Jones, 1992)

Message creation	Digitized	Synthesized
Setting is noisy	No	Yes
User is an accomplished speaker	Yes	No
User has advanced technical skills	No	Yes
Message requires editing	No	Yes
Computer memory is restricted	No	Yes
Message has untypical pronunciations	Yes	No
Message is confidential	No	Yes
Speed of creation essential	Yes	No
Task is arduous (but not spatial)	Yes	No
Prosodic features essential for meaning	Yes	No
Complex message	No	Yes
Message reception		
Speaker must be identified	Yes	No
Noisy environment	No	Yes
Receiver is overloaded with information	Yes	No
Visual display or print-out necessary	No	Yes
Message is lengthy	Yes	No
Message carries warning/alerting function	No	Yes

The speech warning should be loud enough to be clearly intelligible in all anticipated operating environments (Lerner *et al.*, 1996) [12]. The appropriate intensity level for speech warnings depends on the noise level in the ambient environment, the distance of the speech source from the driver, characteristics of the speech signal, the design of the speech system, and other factors.

The voice of speech output can be a natural sounding voice, if the voice characteristics of speech displays can be easily differentiated from other speech in the vehicle, and the voice can be perceived in the noisy environment of a car. Processing of synthesized speech seems to impose greater demands on cognitive processes than does natural speech. Male or female voices can be used.

The speech warning should be loud enough to be clearly intelligible in all anticipated operating environments. Speech warnings should be as brief and concise as possible, but sufficient contextual information is required for accurate speech perception.

6.4.2.2 Message length

Generally, more time is required to deliver a speech message than to alert the driver through other modes. For this reason, speech displays are not recommended for presenting specific information of a dynamic nature (Lerner *et al.*, 1996).

12) Lerner *et al.* (1996) discuss the characteristics of speech output for crash avoidance warnings. These recommendations are generalized here to other warnings in vehicles as far as sensible.

According to Lerner *et al.* (1996), speech warnings should be as brief and concise as possible. There is limited time available for the presentation of speech messages in time-critical situations. Therefore, messages must be short, generally between one and three words.

However, in applications where time availability is not a critical factor, longer messages are preferred, because they allow the listener to accommodate to the synthetic speech, thereby increasing its intelligibility (see 6.4.3.3, Simpson and William, 1980). Although this “ramp-up” time is short, it is normally desirable in other contexts in which time pressure is minimal (Rosson, 1985).

Speech messages can be abbreviated in order to reduce presentation, but sufficient contextual information is required for accurate speech perception. Simpson and Navarro (1984) suggest that voice warnings should comprise short phases of a minimum of four to five syllables to minimize observer attention and to ensure intelligibility in the presence of background noise. Hence, it appears that the use of speech warnings in time-critical applications has severe limitations.

6.4.2.3 Pitch, word rate

Simpson and Marchionda-Frost (1984) presented pilots with threat warnings, to which they were asked to respond as they participated in a complex simulated flying task. The speech warnings were presented at three different fundamental frequencies (70 Hz, 90 Hz and 120 Hz fundamentals) and three different speech rates (123, 156 and 178 words per minute) in a fully factorial design. Reaction times, measured from the start of the onset of the voice warning to the point where the pilot began to take action, showed a significant effect for speech rate, but no similar effect for pitch. Reaction times were fastest for those warnings presented at the fastest rate. Whether this is caused because more words can be conveyed in a shorter period of time, or because the faster presentation rate may result in greater perceived urgency remains an issue for exploration.

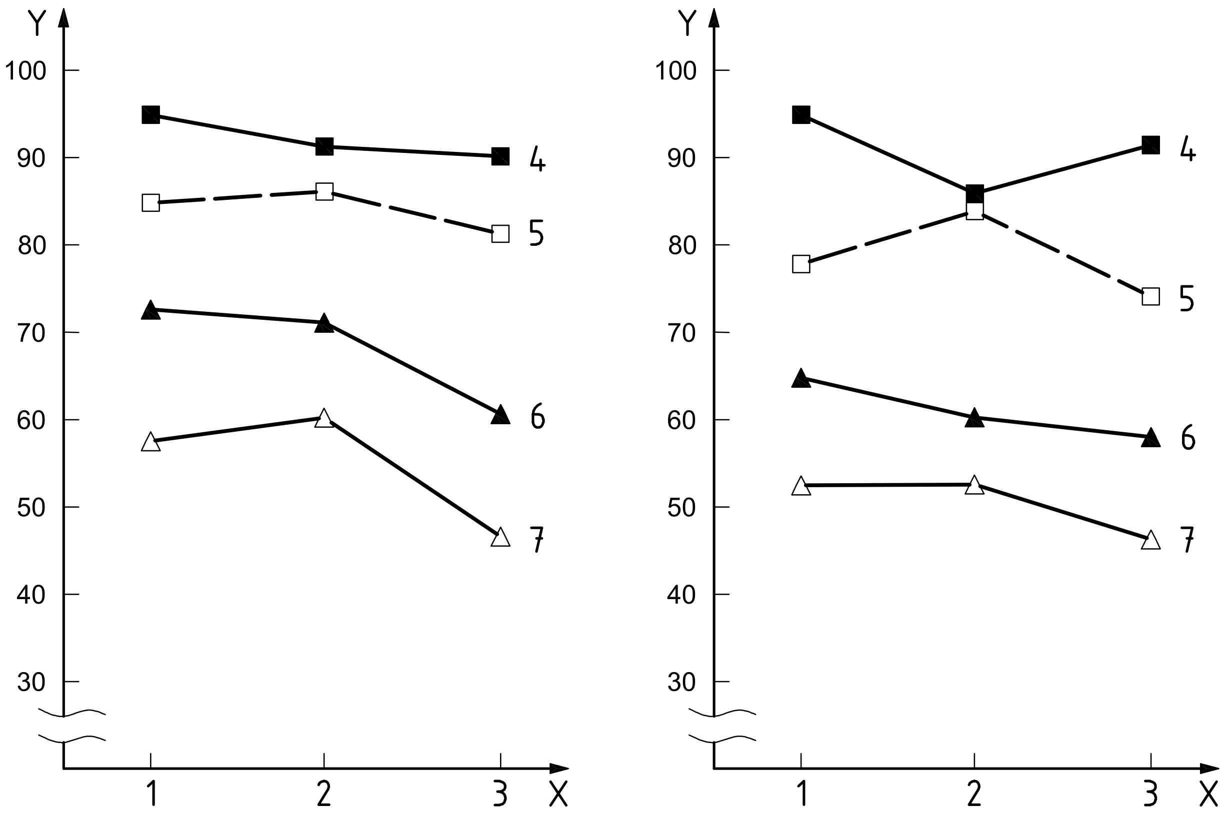
Pilots also rated the warnings on semantic differential scales, from which it could be concluded that they marginally preferred the warnings presented at 156 words per minute, fearing that they might miss messages presented at a higher rate.

The intelligibility issue was explored in further detail by Slowiaczek and Nusbaum (1985). Participants were asked to transcribe synthesized voice messages, which were presented at a rate of either 150 or 250 words per minute. In addition, the messages were presented either with a flat pitch contour (as a monotone) or with a natural pitch contour superimposed upon them. The results show that the messages presented at the slower rate were more accurately recognized than those presented at the faster rate (see Figure 15). It also shows that those messages in the ‘short’ format (sentences were presented in two different lengths, ‘short’ and ‘long’) produced higher percent correct rates than those in the ‘long’ format, which might be expected. There was an effect of the type of sentence (one of three types: active, passive or centre-embedded), and there was a smaller, but significant effect of pitch contour (inflected vs. monotone). The nature of this effect was that the messages presented in the ´inflected´ condition produced higher scores than those presented in the ´monotone´ condition.

The recommended frequency range for in-vehicle auditory speech signals is 200 Hz to 8 000 Hz (Heller and Krüger, 1996).

Simpson and Marchionda-Frost (1984) recommend a speech warning rate of 156 words per minute, although slightly higher rates (up to 200 words per minute) may be used, e.g. 2 to 3 words per second (NHTSA, 1996).

Higher speech rates and short messages result in faster and more accurate reactions. The introduction of a pitch contour seems to produce a small improvement on the intelligibility of speech but does not appear to be as important a factor as some of the other factors relevant to the design of speech messages.



a) Inflected

b) Monotone

Key

X syntactic complexity

Y percent correct

1 active

2 passive

3 centre-embedded

4 short, slow

5 long, slow

6 short, fast

7 long, fast

Figure 15 — Percentage correct identification for different speech signals (Slowiaczek and Nusbaum, 1985)

6.4.3 Coding parameters

6.4.3.1 Vocabulary

The vocabulary used for speech messages should be limited in size and should consist of words which can be easily discriminated from one another (Lerner *et al.*, 1996). Since messages must be brief and the driver will have little time or opportunity to adapt to synthetic speech, the vocabulary must be limited. Because short messages will be presented in isolation, the driver will not be able to identify the words based on context cues. The vocabulary therefore should consist of words that are easily discriminated by the driver.

Hart and Simpson (1977) have demonstrated that polysyllabic words are more easily recognized than monosyllabic words in some contexts and environments.

The content of speech messages (e.g. of crash-avoidance warnings) should be limited to that which alerts the driver to the situation and directs the driver's attention to its location (Lerner *et al.*, 1996). Given the limited time available to convey, for example, crash-avoidance messages via the speech mode, the alerting function should be exploited. Because direction can be conveyed easily with minimal vocabulary or through the location from which the speech appears to emanate, directional information may also be conveyed. More complex forms of information (e.g. time-to-collision or distance-to-collision) should not be incorporated into speech messages.

Several rules can be used to construct the vocabulary forming an auditory message (Heller and Krüger, 1996; Galer and Simmonds, 1984).

a) The total vocabulary should be as small as possible; the fewer the alternatives, the greater the intelligibility.

b) Words as information units must distinguish between different information types or categories; that is, they must uniquely define the subject or category.

c) The words should be familiar, i.e. the vocabulary of each category must be controlled, according to a lexicon[13)].

d) The vocabulary must be homogeneous and consistent within a category and between categories.

e) The vocabulary must be based on stereotypes regarding meaning within the target population of users[14)].

f) Critical words should be embedded in a context, i.e. phrases or sentences.

g) To obtain words that are easily distinguished, polysyllables should be selected. The more syllables in a word, the more likely it is to be heard correctly.

h) Words with easily confused sounds, e.g. “P” and “T”, should be avoided.

A more general specification for the words of a verbal message is given in the standard for military aircraft MIL-STD-1472C: in selecting the words to be used in the message, priority shall be given to intelligibility, aptness and conciseness in that order (Doll and Folds, 1985).

Graham *et al.* (1995) observed in their experiment with a Collision-Avoiding System (see 6.3.5.5), that a speech warning (“ahead”) gave faster reaction times in the “stationary vehicle ahead” scenarios, but slower reactions for the car pulling out from side road scenarios. This is not surprising in that the extra directional information given by the “ahead” warning is likely to cause the driver to orient to the road ahead rather than to the sides of the road. Subjects also made comments to this effect. This behaviour is clearly advantageous if the potential collision is in the road ahead, but detrimental if it is to the side.

For a Collision-Avoiding System that is unable to discriminate different types of headway-collision situations, a generic warning is required. A specific speech warning may not be applicable across all situations and therefore may be inappropriate for such a generic warning. On the other hand, where a system is able to discriminate the location of the potential collision, a speech warning can provide extra directional information and help the driver discriminate different collision situations. Within automobile applications, the speech vocabulary must be the same as the written vocabulary, except in rare cases, such as when the written vocabulary includes unpronounceable abbreviations or when there is some risk of auditory confusion between two words (Heller and Krüger, 1996).

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13) Controlled lexicon: The intelligibility of spoken messages is higher when the messages come from a fixed and known vocabulary rather an “open” vocabulary (Werkowitz, 1981).

14) Stereotypes: An experiment of Simpson (1975) showed that the intelligibility of synthesized messages can be enhanced by using words and phrases with which pilots are familiar.

Speech technology may incorporate multiple language options. Warning vocabularies and messages should be developed and tested separately for each language to be represented within the system. It can not be assumed that words that are highly discernible in English will be highly discernible in other languages (Lerner *et al.*, 1996). Vocabularies and speech messages must be developed and tested separately for each language to be employed in a crash-avoidance warning application.

There are some well-established rules for the vocabulary in spoken messages (e.g. brevity, specificity, familiarity, etc.) The vocabulary must be based on stereotypes and be controlled (i.e., fixed and known.) The words should be polysyllables. These are essential factors for intelligibility, aptness and conciseness of a vocabulary of speech output. Speech warnings should represent the specific driving situation about which they are warning, but in cases where specific information is not available, generic warnings have to be implemented.

6.4.3.2 Intelligibility

A speech system should demonstrate a high level of intelligibility in tests using isolated words (Lerner *et al.*, 1996). Candidate systems should demonstrate high intelligibility of the specific vocabulary to be used in the warnings.

Due to the small vocabulary and limited message length, intelligibility measures based on conversational speech intelligibility will be less relevant in choosing a system based on the intelligibility of isolated words (Moore, 1987). In addition, synthetic speech systems, which are largely rule-based, differ from one another with respect to the pronunciation and intelligibility of individual words. Although many systems exist which have merited high scores on intelligibility tests, a confirmation of the specific vocabulary to be used is, nevertheless, recommended. Studies also indicate that high-quality synthetic speech systems are generally more intelligible in noisy environments (Nixon, Anderson and Moore, 1986).

6.4.3.3 Linguistic redundancy, preceding tone

Simpson and Williams (1980) found that the more semantically-rich format warnings (the three or four word warnings, rather than the two or three word keyword format) did not produce slower reaction times, even though they were an average of 0,3 s longer than those in the keyword format. This replicates an earlier finding (Simpson and Hart, 1977). In fact, responses to the keyword format were slower than they were to the semantically-rich warnings, although not significantly so. Greater redundancy of information in the warning reduces processing time per word, which also decreases the amount of attention required in processing the message. Thus semantically-rich voice warnings might be particularly useful under high workload conditions.

The linguistic redundancy is even more important in noisy environments: Hart and Simpson (1977) compared the intelligibility of synthesized warning messages in sentence format versus two-word (keyword) format. They found the sentence-format message to be more intelligible in various conditions of background noises. This format required less attention for comprehension. These findings were in conflict with the subjective statements of pilots who preferred the keyword format, presumably because they believed response time to the keyword messages would be quicker.

Heller and Krüger (1996), however, pointed out that as the length of an auditory message increases, so do the imposed demands on attentional resources and short-term memory. Because of these and other limitations associated with human information processing capacity, the number of information units from which a message is composed should be limited. Moreover, it takes a finite time to deliver a complete message and the message may not be understood until the delivery is complete. Therefore, the more critical the driving situation is, the shorter the message must be (see 6.3.6.2).

It is recommended that a speech output should be announced by a short auditory signal (Voss and Bouis, 1979), specified for military aircraft in MIL-STD-1472C (Doll and Folds, 1985). A verbal warning shall consist of an initial non-speech signal to attract attention. A tone preceding the speech output, however, increases the total time for response from event occurrence to correct response (e.g. 5,1 s to 5,8 s) (Boff and Lincoln, 1988).

Simpson and Williams (1980) tested the pilot's response time in a flight simulator with four commercial pilots. They found that the response time to a warning signal was shortened when the verbal message was preceded by an alerting tone (0,5 s for the tone and 0,5 s of silence to preclude forward masking).

Semantically-rich format should be preferred to keywords. Research has shown that the overall time (speech + processing + reaction time) does not increase proportionally to number of words.

Greater redundancy of information in spoken warnings decreases the amount of attention required in processing the message. So, warning messages should be presented in sentence format, but should be as short as possible with an announcement tone with a pause of 0,5 s between announcement and message. For very urgent messages, however, the amount of time taken for message delivery has to be taken in consideration.

An alerting tone should not be used preceding voice messages unless its benefits in the crash-avoidance context can be demonstrated.

6.4.4 Organizational parameters

6.4.4.1 Message repetition

Voice messages should not be repeated numerous times because of their tendency to irritate the driver and upset passengers. Voice messages will be more disturbing, particularly to passengers, than any other type of warning, if repeated frequently in succession. In addition, the potential for embarrassing the driver and creating a panic situation is greater for speech displays than for other displays.

A given speech warning should be presented no more than three times, e.g. for a given crash-avoidance warning situation, regardless of the duration of the situation (Lerner *et al.*, 1996). Repetitions should occur in immediate succession. If the duration of the crash-avoidance condition is less than the time required to deliver the three presentations of the speech message, the speech message should be terminated when the crash-avoidance situation terminates.

The three-presentation limit is based on the Traffic Collision-Avoidance System (TCAS) used in aviation, which also provides two and, for some messages, three presentations of collision-avoidance warnings and instructions (Federal Aviation Administration, 1990).

6.4.4.2 Urgency

The information part of a warning is that part which enables the recipient to make the decision as to whether or not to comply with a warning. The iconic part, i.e. the prosodic features, provokes some more basic response. It can be expected that the perceived urgency of a spoken warning will be influenced by the prosodic attributes, such as pitch, speed and intensity of the message (Edworthy, 1994) [15]. In spoken messages the informational and the iconic aspects can be readily dissociated (Edworthy and Adams, 1996).

15) The atonal, repetitive pitch contours used by trained speakers whose job is to give out information in environments such as aircraft provide anecdotal support for the view that pitch contour might have some importance in the perception of urgency. Airline stewardesses start off each new statement at a relatively high pitch, fall throughout the statement, with one or two rises along the way, until they reach a low pitch and the end of the statement. Everything they say follows this same pattern. We cannot thus differentiate between a bland statement about the purchasing of duty-free goods and the essential safety information that we also receive, at least in iconic terms

The delivery of a complete message takes time and the message may not be understood until the delivery is complete (see 6.4.3.3, Heller and Krüger, 1996). Thus, the more critical the driving situation is, the shorter the message must be.

a) **Urgent action**: A message which requires an urgent response by the driver must be understood immediately. Consequently, it must consist of a short phrase (with fewest possible syllables) or a tonal signal (Heller and Krüger, 1996).

   EXAMPLE "Stop", "Slow down".

b) **Delayed action**: A message which can accept a delayed reaction can be composed of several units of information. In the case of complex auditory information, it is necessary to help the driver in different ways (Heller and Krüger, 1996).

   1) Sequence the units of information in order of potential relevance to help driver to quickly decide whether to 'tune-in' or 'tune-out', depending on message content.

   2) Exploit echoic memory by placing the action-related unit of information at the end.

   3) Provide prosodic cues and highlighting.

   4) Provide redundant visual displays.

   5) Provide a means for the driver to request that the message be repeated.

It can be expected that the perceived urgency of a spoken warning will be influenced by the prosodic attributes, such as pitch, speed and intensity of the message. There is, however, very little experimental data on this topic. Urgent actions have to be signalled by short phrases (if tonal signals are excluded for any reason). For situations in which delayed actions are acceptable, messages can be composed of several units of information, which have to be structured and designed according to specific rules, like sequential presentation, redundancy, including prosody, etc.

The minimum intensity to which a system or device is adjustable must still be readily perceptible to the non-hearing-impaired driver. Devices should be tested to determine the appropriate value for minimum intensity.

Auditory signals should not exceed a maximum of 115 dB (A-weighted).

To accommodate drivers with hearing impairments and to accommodate a wide variety of driving environments, the capability to adjust the intensity of auditory displays must be provided, even if automatic, adaptive volume control is provided.

6.4.4.3 Prioritization

Auditory messages can not be presented concurrently but have to be prioritized. In a survey of commercial pilots, Veitengruber *et al.* (1977) report that pilots want the aural alerts (tones/speech) to be prioritized, and they want the priority level to be indicated by the characteristics of the warning so that an immediate assessment of the situation's urgency can be made.

Priorities between information categories and within a specific category must also be pre-defined in vehicles (Heller and Krüger, 1996). These priorities strongly depend on the particular systems: area of messages that could be competitive, what messages could be competitive, in which specific situations, etc. For example, the highest priority is accorded to messages that require action. Within this category, a message concerning collision risk has a general high level of priority.

A system of information prioritization must be implemented to ensure that the most important information is unblocked by other messages and available for immediate presentation to the driver at all times.

6.4.5 Warning applications of speech output

Simpson (1980) suggested a number of potential applications of synthesized speech to replace or supplement visual information for military aircraft. Analogous applications for (civil) vehicles can be derived: while synthesized speech can be used as an approach call-out system (glide slope intercept, altitude above field etc., usually given by the pilot not flying), an analogous system in ground vehicles is ACC (see 10.2). Spoken warnings can be given at different points when approaching a preceding vehicle and can specify the different criticalities. This could extend from a soft approach to a relatively far object to a fast approach to a near object. The criticality of different situations can be expressed by the content, word rate and pitch of the speech [16)].

Awad (1988) gives an overview of some possible applications of voice output in the vehicle [17)]. Speech output can be used to warn the driver about hazards and malfunctions in the vehicle. The function of the warning system is to periodically monitor a set of physical quantities and the status of certain devices in the vehicle. If an abnormality is detected, the system issues an appropriate warning to the driver. The warning has three phases of operation. The first phase starts upon the driver's initial entry into the vehicle. When the ignition is turned on, the warning system monitors the seat belts and possibly other conditions.

In the second phase, when the engine is running, the warning system monitors the doors, engine temperature, electrical system, trunk, fuel level, parking brake, and possibly other functions. A sample message could be: “Your engine is overheating. Prompt service is required”. Speech output can also be used to direct the driver's focus to a nearby vehicle, which is detected by a side-obstacle warning system (see 10.3). Here, the localization of this potentially “dangerous” vehicle can be specified by speech output or a tonal signal [18)].

The third and final phase begins when the driver turns the ignition off. In this phase, the warning system monitors the ignition key and the headlights in order to remind the driver to take appropriate action if he forgets his keys or leaves the headlights on. In the event that the warning system detects more than one abnormal condition, the system must decide which of the warning messages has the highest priority and deliver it.

Moreover, it must be noted that some conditions need immediate action (as in the case of a door being opened), whereas other conditions may have to be monitored for a relatively longer interval. A good example for the second case is the battery voltage of the vehicle.

An additional feature of the warning system is that it can mute the radio in order to deliver a message. Also, the driver should have the ability to turn the system on and off and, where volume controls are available, should be able to adjust the volume above a minimum level. This is important to the driver because it gives him the opportunity to adjust the sound level to his preference or even turn it off in case it becomes annoying.

16) Another recommendation of Simpson (1980) to use speech output is to specify the data about the destination airport and assistance to the pilot in entering his flight plan. The analogy for automobiles would be a driver´s assistance to enter data in a navigation system, which is already realized and beyond the scope of warning messages.

17) The author discusses speech output (and input) from the state of the art of 1988. Nevertheless, these examples still hold true for the present.

18) In another application, voice output can be used to help the driver of manual transmission automobiles to improve the fuel efficiency. It has been determined that incorrect gear shifting can decrease the fuel economy. Voice output is used to tell the driver when to shift.

Speech output is efficiently used in military aircraft for different warning functions, e.g. glide slope intercept, altitude above field, etc. Similarly, it should be introduced in vehicles to make use of its specific alerting and informational advantages. Though the applications may range from situations before to after driving, its main usefulness is during driving. Here, basically all sorts of warnings can be presented in spoken form, i.e. from short-term urgent ones as side-obstacle warning to more long-term ones of vehicle's status. However, care must be taken not to overload this channel and a priority system has to be installed. The control of the speech output system by the driver has to be ensured.

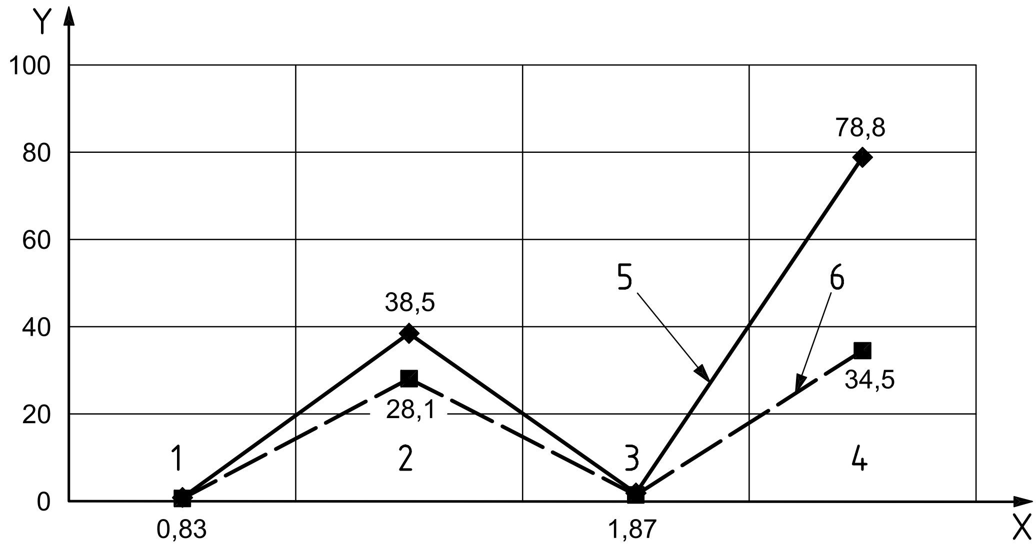
6.5 Comparison of tonal signals and speech output

In an Intensive Care Unit (ICU), non-verbal audible signals are employed to convey information of a critical nature from instrument to medical personnel (McIntyre and Nelson, 1989, see 11.2). A laboratory investigation of automatically-delivered human voice signals for an intensive care unit with two mechanical signal tapes (tonal signals) and two speech outputs was conducted. The two mechanical signal tapes contained recordings of six mechanical alarms built into patient monitoring units. The alarms communicated deviations from acceptable heart rate, cardiac rhythm, arterial pressure, etc.

The two verbal signal tapes contained spoken statements describing the bed location and type of emergency. There were four conditions called: “Slow Mechanical”, “Quick Mechanical”, “Slow Verbal” and “Quick Verbal”‘. The statements were: “Look at bed — check oxygen level”, “Look at bed — check ventilator”, etc.

Results (see Figure 16): More errors were observed for mechanical signals (28,1 % to 78,8 %) than for verbal signals (0,8 % to 1,9 %). The verbal signals were overwhelmingly superior as compared to the mechanical ones. It is proposed that the consistently high error rates with non-verbal signals were due to uncertain memory. It can be reasonably certain that the practice procedure was adequate to provide perfect recognition during practice, but that memory was unreliable during the testing sessions for mechanical signals. Thus, there is little doubt that a greater amount of practice would improve performance for mechanical signals. However, given any practical amount of practice, it seems almost certain that verbal signals will retain a large superiority. Based on short-term memory research, it is likely that increasing the number of types of signals beyond six would impair performance to a greater extent than was measured (Miller, G.A., 1956).

These results are consistent with the results in a military flight simulator (Boff and Lincoln, 1988). The bombing mission flight included simulated noise and communications. Emergency warnings occurred as master caution lights with tones or verbal messages presented with a female voice, which were repeated until pilot depressed the master light. The summarized results were that tone warnings required the operator to refer to the legend of a supplementary light signal or to memorize tone meaning for event identification. In contrast, voice warnings provided explicit information about problems. Response times to most voice warnings were faster than response times to tone warnings. In addition, pilots preferred the voice warning system.



Key

X signal character
Y percent correct identifications

1 slow verbal signal
2 slow mechanical signal
3 fast verbal signal
4 fast mechanical signal
5 standard
6 burst

Figure 16 — Percent observed errors of medical signals (McIntyre and Nelson, 1989)

Signals should be classified according to the urgency of the drivers intended action. Three time-related categories seem to be justified (Heller and Krüger, 1996).

— Category "immediate": Immediate action is required. A message must be sent to the driver immediately after the critical event is detected.

  — EXAMPLE An obstacle on the road is detected. The driver should brake immediately.

— Category "short-term": The action must take place within a short time (10 s to 20 s). Messages of this category can be sent with a time delay.

  — EXAMPLE Route-guidance information.

— Category "long-term": A future behaviour is expected. Messages of this category can be sent with a time delay. The time until the driver reacts to the message can be chosen within broader limits.

  — EXAMPLE Not enough wash water for cleaning the windows.

Referring to these time-related categories, the choice between non-verbal and verbal auditory signals could be made according to Table 21 (Heller and Krüger, 1996).

Table 21 — Categories of time-related signals

Category	Tonal signal	Speech
Immediate	Suitable	Not recommended
Short-term	Suitable	Suitable
Long-term	Total announcement of verbal message or a visual display	

To differentiate between the time categories, different patterns of acoustical parameters can be chosen (e.g. loudness, frequency). In the environment of military aircraft, cues are necessary by which the urgency of the signalled condition can be quickly discerned. As a result, precious time in critical phases of flight can be saved (Doll and Folds, 1985). In a survey of commercial pilots, Veitengruber *et al.* (1977) report that pilots want the aural alerts (tones/speech) to be prioritized, and the priority level to be indicated by the characteristics of the warning, so that an immediate assessment of the urgency of the situation can be made.

Auditory signals can be classified according to the urgency of the drivers intended action, i.e. immediate, short-term, and long-term. Both the mechanical auditory signals (tones, auditory icons) and the oral speech coding (speech output) have advantages and disadvantages with regard to the amount of information, necessary knowledge, time consumption etc., as discussed in the previous Clauses. These led to the recommendations shown in Table 22 (Van Cott and Kinkade, 1972; Galer and Simmonds, 1984).

Table 22 — Recommendations for auditory signals

Use tones	Use speech output
... when the message is extremely simple	... when flexibility of communication is necessary
... to specify a moment	... when the source of the message has to be identified
... when the signal designates a point in time that has no absolute value	
... when immediate activity is necessary	... when the message deals with a time-related, but not immediate activity
... when speech signals are over-burdening the listener	
... when noise conditions are unfavourable for receiving speech messages	
... when speech will mask other speech or annoy other listeners	... when rapid two-way exchanges of information are necessary
... if the user is trained to the tones	... if the user is not trained to the tones
	... when stressful situations are possible which can cause tone codes to be forgotten

7 Tactile warnings

7.1 Advantages of tactile presentation

Multiple-resource theory proposes that attentional resources differ along several dimensions, including stages and codes of processing as well as input/output modalities (Wickens, 1992). Cross-modal task and information presentation should therefore lead to more efficient processing and improved task-sharing performance (see Clause 4). In tasks like flying and driving with high visual workload, information should be distributed across various sensory modalities, including the tactile modality (Sklar and Sarter, 1999).

Proprioceptive-tactile warnings transmitted via the control element have the advantage of direct intervention into the manual control process. The receptors of the information synchronously serve as effectors for the action indicated by the stimulus information (perceiving-acting compatibility). Additionally, the timing of the warning can be controlled immediately with the driver's actions without further delay (Schumann, 1994).

Tactile displays are most commonly utilized in aircraft. Examples include the stick-shaker (indicates proximity to a stall), foot-thumper (indicates cycling of the anti-skid system), and stick-pusher (assists the pilot in reducing the danger of a stall).

However, tactile displays are not currently widely used in automobiles, although there are a couple of examples, such as applying counter-forces on the accelerator and brake pedals. Schumann (1994) attached a servomotor to the steering column, which can be used to influence the regular steering torque artificially to transmit proprioceptive-tactile cues to the driver which signal an affordance to react to the appropriate steering actions. Thus, the steering wheel conveys feedback concerning lateral control aspects to the driver and consequently serves also as a proprioceptive-tactile display (see 10.2).

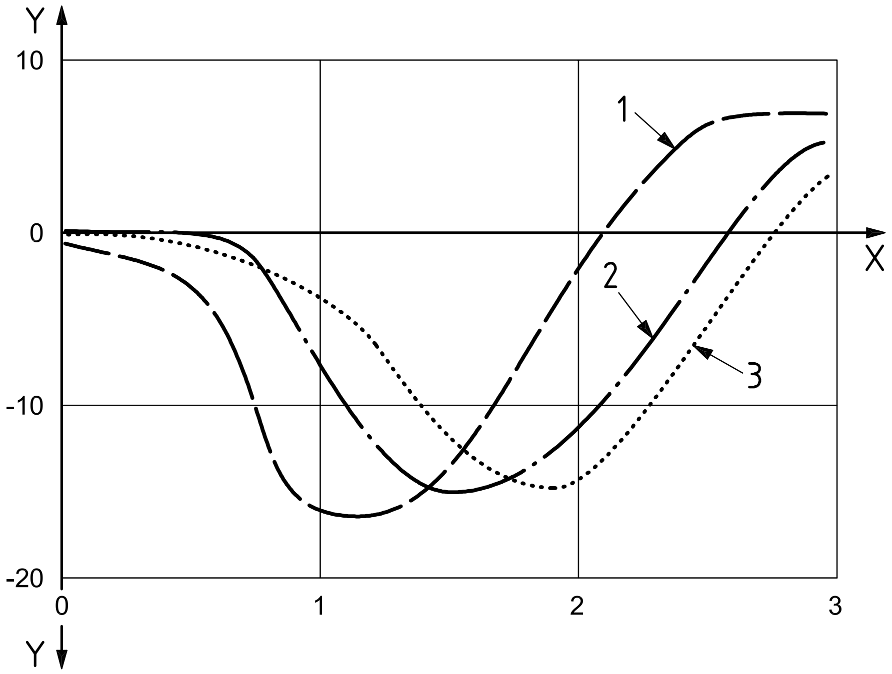
SAE ARP 450 (1971) requires that the use of tactile displays be minimized. In addition, Veitengruber *et al.* (1977) note that tactile warnings are not recommended in the commercial transport environment because they are disruptive.

The driver should be able to form a natural association between the tactile display and the situation it represents and, possibly, the appropriate action to be taken in response to that situation (Lerner *et al.*, 1996). For example, accelerator pedal pressure may provide an appropriate crash-avoidance display for headway warning situations where the driver must slow down or brake (Nilsson, Alm and Janssen, 1991). It would probably be less effective as a display in the case of a blind spot device or a drowsy driver-alerting device. Among the possible tactile display locations in an automobile are the steering wheel, the accelerator pedal and the driver's seat (i.e. bottom and back).

In a series of on-road experiments of PROMETHEUS, strategies for warning drivers were investigated (Breuer *et al.*, 1994, see Clause 8). They reported a very high acceptance of restoring force to indicate a certain warning level to the driver with adverse street conditions. Here, the frictional connection between tyres and the road is more difficult to assess and a warning given via foot was judged positively. The tactile warning at the accelerator pedal and the combined lamp and gong were comparable with respect to high conspicuity, clarity, and relatively moderate startling effect, distraction and influence. It is worthwhile stating that there was a considerable standard deviation of the judgement of distraction for the tactile mode but a rather unanimous judgement of the high conspicuity.

Sato *et al.* (2001) conducted studies with the STAR (STeering Assist & Robust) system developed as a lane-departure warning/lane-keeping assist system to assist drivers' steering operations in the lateral direction. The basic concept of the steering control is to apply a torque to guide back any vehicle approaching the lane boundary. Two ways of applying the torque were studied. The first way was to apply a pulse-like torque change which functions as a warning rather than an assistance ("warning by torque"). The second way was to start applying the torque when the vehicle enters the control zone, and increase the torque applied as the vehicle approaches the lane boundary ("torque assist").

These torque variants were compared with a warning by sound (see Figure 17). Ten test drivers drove a vehicle at 100 km/h. While the test drivers implemented the corrective steering as soon as a warning by torque was issued, the response time to the corrective steering was about 0,6 s for the warning by sound. In the case of the torque assist, the corrective steering was delayed because the torque assist was a function designed to gradually increase the torque applied, and there was some time before the driver felt the change in the torque. The torque assist was effective in moving the steering in the direction of guiding back the vehicle to the centre of lane and without the sense of unpleasantness. The maximum lateral displacement from the centre of lane was the shortest for the warning by torque (1,06 m), followed by the warning by sound (1,27 m) and the torque assist (1,33 m).



Key

X time, in seconds

Y steering angle, in degrees

1 warning by torque

2 warning sound

3 torque assist

Figure 17 — Comparison of effects among warning by sound, warning by torque and torque assist

Information in vehicles should be distributed across various sensory modalities, including the tactile modality. Proprioceptive-tactile warnings transmitted via the control element have the advantage of direct intervention into the manual control process. There is a good acceptance of tactile warnings given at the accelerator pedals. The judgement is comparable to a visual/auditory warning combination. Pulse-like torque onto the steering wheel is superior over a warning sound as a lane-departure warning. A number of important questions still remains to be explored in future investigations.

7.2 Design parameters

7.2.1 Sensorial-related parameters

Vibration frequencies of 100 Hz to 300 Hz should be used, because humans are most sensitive to vibration in the 100 Hz to 300 Hz range (Lerner *et al.*, 1996; Verrillo, 1966). Frequencies within this range are also unlikely to be masked by road-induced vibration of the vehicle, which generally occurs at a lower frequency.

Vibration frequencies of 3 Hz should be avoided. A vibration frequency of 3 Hz is the resonating frequency for the internal organs of the human body. A vibro-tactile display which matches this frequency may cause nausea and discomfort and, thus, should be avoided.

Display intensity should be 20 dB to 30 dB above masked vibratory threshold, as measured in the vehicle under all anticipated normal driving conditions (Gilson, 1992). The intensity of the display should be sufficient to alert the driver without creating a startle effect or interfering with performance of the driving task. Consideration should be given to roadway vibration, vehicle vibration (e.g. luxury car versus commercial truck), clothing worn by the driver (e.g. heavy gloves, boots, etc.) and vehicle seat covers (e.g. sheepskin, wooden beads, etc.).

Vibro-tactile displays may be of two types, continuous or pulsed (Lerner *et al.*, 1996). The on-off cycle for pulsed displays must be determined through testing, since insufficient data exist to recommend a value. Pulse rates will likely be application-specific, depending on the location of the display.

Vibro-tactile displays, once activated, should cycle continuously until, for example, the crash-avoidance situation no longer exists, the driver has taken appropriate corrective action, or the display has been manually terminated.

7.2.2 Coding parameters

Geldard (1962) employed three dimensions of vibration stimuli for coding intensity, duration, and location. By combining various levels of these dimensions, he developed a code made up of 45 distinct vibro-tactile patterns. An average subject was able to receive these at a rate of 35 words per minute, which compares favourably with the expert rating of 24 words per minute for a Morse Code operator.

There are relatively few and no verified recommendations as to the parameters of tactile displays. These concern the frequency, intensity, duration and pulse rate. If vibration stimuli are coded by intensity, duration, and location, the user can recognize more words per minute than with a Morse Code.

8 Redundancy of message presentation

Redundant information is present when there is more than one source of the same information. Redundant information can occur in several ways (Boff and Lincoln, 1988).

— There may be repeated signals.

— The signals may be in different codes.

— The signals may be in different sensory modalities.

Generally, the presence of redundant information decreases reaction time (Boff and Lincoln, 1988). This 'Stroop effect' means a facilitation when the secondary source of information is congruent with the primary source (Dyer, 1973). It implies that information is being integrated, e.g. across the two modalities, thus affecting the resulting perception. This performance gain can be equivalent to that achieved with a 10 dB increase in the signal-to-noise ratio (McLeod and Summerfield, 1987). Vice versa, the presence of an incongruent secondary source of information interferes with the processing of the primary information, producing increased task completion times.

The robustness of the Stroop effect, coupled with the fact that it can produce facilitation as well as interference, gives it potential utility in the design of information displays for time-critical real-world tasks in dynamic environments. This is particularly relevant in the aviation and ground traffic environment where even small time savings can be vital in the interpretation of safety critical displays, e.g. high-priority, immediate-action cockpit warnings where a response may be required within 1 s to 2 s (Selcon *et al.*, 1992).

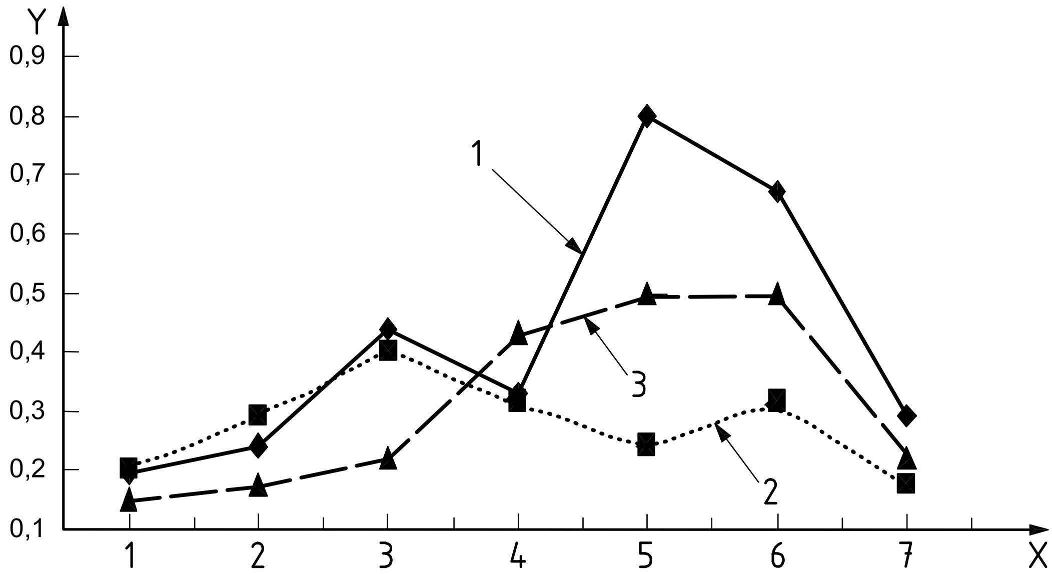
8.1 Visual/auditory combination

According to the Stroop effect, non-speech auditory displays in combination with visual displays can be very powerful information transmitters (Galer and Simmonds, 1984). For example, a visual warning symbol plus an auditory signal will have the advantage of drawing to the driver's attention the fact that there is a fault and the warning symbol can indicate the nature of the fault. In navigation, an in-vehicle computer-generated map and command display could be supplemented by an auditory command display, which could make it possible for the driver to navigate in congested areas without visual diversion. Later, when conditions permit, the driver could update the perceived location and direction using the visual display.

Erlichman (1992) conducted a pilot study with alternative signalling presentations and symbols for the Driver-Alert Warning System (DAWS) designed within the In-Vehicle Safety Advisory and Warning System Program (IVSAWS). Thirteen subjects were exposed to new pictograms and were requested to verbalize their understanding and preferences in regard to varying signalling characteristics. These characteristics included: a) monochrome; b) colour; c) blink; d) tone; e) text message; and f) voice message.

Figure 18 shows the preference by age group. In general, the results showed a preference for the voice (long/short) and text message associated with each pictogram, i.e. CTTV = Colour, Audio Tone, Text, Visual message by the subject groups. The figure clearly shows that the preference for text and voice messages was more highly preferred by the 16- to 30-year-old (Young) age group, followed by the 51-year-old and over (Mature) age group.

The category “Colour + Blink” indicates a preference by the female subjects, because blink or flash was interpreted to be the presence of a more immediate danger. The male population believed that more information would be worthwhile thereby allowing the driver to take the most appropriate action.



Key

X warning designs

Y preference (preference index = 1/mean rank

1 monochrome

2 yellow background

3 colour and blink

4 colour and sound

5 CTTV long

6 CTTV short

7 alternate symbols blink

8 16- to 30-year-old age group

9 31- to 50-year-old age group

10 51-year-old and over age group

Figure 18 — Preference of warning designs by age group (Erlichman, 1992)

Visible and audible techniques are frequently combined in industrial plants to signal the degree of urgency (Krigman, 1985, see 11.3). A three-level light and sound priority system is used in a gas pipeline industry: alarms of the greatest urgency are accompanied by flashing lights, bells, and logs, e.g. alarms requiring shutdown. The conditions are monitored to be sure they have cleared after acknowledgement. The second level provides the same output, but the conditions are not monitored. The third priority uses flashing lights and logs, but no bells and no check for clearance of acknowledgement. A fourth priority produces logs but no lights or bells.

Parallel presentation of tones and visual signals are not always related to each other (Voss and Bouis, 1979). If tones are not well-known, they can be misinterpreted and are not necessarily associated with the equivalent visual signals by users. Usually they are interpreted as general warning signal and induce a glance at the instruments. Sometimes, however, they lead to an understanding such as “I am driving incorrectly” (in an experimental situation).

Verbal auditory signals used in conjunction with visual signals significantly decrease reaction time when compared to visual signals only (Stroop effect, see above, Boff and Lincoln, 1988). A military aircraft was flown with malfunction simulation being realized from different warning equipment. Response times for visual signals ranged from 1,8 s to 762,4 s; response times with added verbal warnings ranged from 1,8 s to 8,1 s.

Selcon *et al.* (1992) described an experiment that used warning/caution icons and verbal warning messages, both singly and in combination. Subjects were required to identify whether the situations presented warnings, i.e. high priority/immediate action, or cautions, i.e. low priority/immediate awareness. The results obtained showed a significant decrease in response latencies when correlated bi-modal information was given as compared to the unimodal conditions. It can be seen from these results, that the provision of a correlated, secondary source of information reduces the time taken to respond to that information. This implies that the redundant secondary source of information is being integrated with the first to facilitate its understanding.

The high level of abstraction of these icons strongly implied that the performance gains occurring must be as the result of the integration of information rather than data. Even though the stimuli are connected in meaning only, the information still becomes integrated. Benefits may also be accrued through reduced workload and increased depth of understanding.

Nemoto and Yoshiura (1995) developed a parking-violation monitoring and warning system with a combined warning approach. The purpose of this system is to automatically detect vehicles that intend to park illegally and to give a warning to the driver to dissuade him from parking. The system adopts a warning method that makes use of human motivation and sense of embarrassment. There is a graduated alarming system with a text warning (“Please move immediately”, sequentially presented words), red revolving lamp, and an audio warning (“Parking is prohibited here. Please move your vehicle immediately.”). Results were not reported.

8.2 Visual/auditory qualities for in-vehicle displays

Uno *et al.* (1999) examined the effects of physical qualities of displays on the perceived criticality and urgency in three experiments.

- In the first experiment, the effects of display determinants on the perceived criticality and urgency were examined in a simultaneous presentation of visual and auditory displays. Two displays were chosen for each sensory modality. Eight display conditions were provided by combining the visual and the auditory display to present both simultaneously. The subjects were asked to rank the display conditions according to perceived criticality and urgency. Results showed that the main effect of the visual display was 57,8 %, the contribution of the auditory display was 41,7 %, and the interaction was 0,5 %. The main effects of each display dominated the total variances of perceived criticality and urgency.

- In the second experiment, some written message words were compared with the effects of the physical qualities. The results showed that the display’s physical qualities dominantly contributed to the perceived criticality and urgency more than the message words.

- In the third experiment, the contributions of display qualities were examined in an actual driving situation by presenting visual and auditory displays to subject drivers while they were driving a saloon car. The reading time and the time interval between the onset of the display presentation and pressing of the horn switch by the driver were both measured. The physical qualities of the displays effected criticality and urgency in the same manner as the results in the second experiment.

The experiments demonstrated that the assignment of physical qualities to the information displays facilitates the smooth communication of criticality and urgency to drivers. It was also confirmed that consideration of the display's physical qualities must be given preference over selection of message words or symbols.

8.3 Visual/auditory indications for displays

Uno *et al.* (1997) described two experiments, which were carried out to examine the effects of various qualities of displays on the nature of the driver's impressions to detect criticality and urgency. To ensure smooth communication of criticality and urgency, relevant forms of indications and displays should be selected in consideration of the level of comprehension by the drivers. Using meaningless visual and auditory displays to examine the effects of physical characteristics, the qualities of the visual display were controlled by means of different levels of colour-luminance, temporal characteristics and spatial characteristics, while the qualities of the auditory display were controlled by means of differences in sound pressure, frequency and temporal characteristics.

The subjects were asked to rank the displays for each of the experimental display sets according to three evaluation items: criticality, urgency and discomfort.

The first experiment was aimed at clarifying the influence of each display characteristic independently from other characteristics. In summary, it may be said that the higher intermittent rate increased the auditory display criticality as contrasted with visual display criticality, where a higher intermittent rate caused a decrease in criticality. The interval scales of perceived urgency and discomfort also revealed the same results excepting that the impression of discomfort was not affected by the luminance conditions of the visual display and the intermittent rate conditions of the auditory display.

The aim of the second experiment was to examine the interactive effects and to estimate the relative contributions of each characteristic. The interactive effects of the display characteristics were examined by means of analysing the variance ratios of the main effects and interaction terms on the total variances. The results of the visual combinations and the auditory combinations showed that the display characteristics interactions were sufficiently small compared with their main effects. The ranges of the distributions varied for the evaluation items.

8.4 Visual/auditory/tactile combination

Visual, tactile and auditory signals can be combined. The combined signals using colour, text, audio tone with or without voice messages are most beneficial. The secondary source of information has to be congruent with the primary source. The Stroop effect is particularly useful in time-critical tasks in dynamic environments. Information should be provided beyond that presented by a pictogram. In a series of on-road experiments of PROMETHEUS, strategies for warning drivers were investigated (Breuer *et al.*, 1994). Depending on the urgency level of the warning, the following modality combinations were used (see Table 23).

Table 23 — Modality combinations used in PROMETHEUS (Breuer *et al.*, 1994)

Function	Modality	Urgency level	Realization
Indication	Visual, auditory	Low	Symbol lamps + gong
Warning	Visual, auditory, tactile	High	Symbol lamps + intermittent tone + accelerator pedal force
	Visual, tactile	High	Symbol lamps + steering wheel vibration

Results were not available.

8.5 Master alerting

The approach in the aviation environment to use a master alerting signal (see 5.3.3.3 and 11.1) can be transferred to warning systems in vehicles (Tan and Lerner, 1995). A single alerting alarm should be used to draw attention to the potential hazard(s) detected by the warning systems. Specifically, it is recommended that a conspicuous and unique warning signal be created that will provide the driver with information that, for example, an imminent crash situation exists and that an immediate corrective action must be made. This unique signal will be used as the master alerting sound, for example, for all crash-avoidance warning devices installed in a particular vehicle. When time for reaction time is very short, a very simple “Danger” may be the only signal that the driver has time to receive (Stevens, 2001). The exact nature of the danger can be deduced from the driving context. Although one can envisage different danger signals for different danger conditions, this may be all too subtle for the driver in crisis.

It is recommended that a single unique warning be selected for the activation of a crash-avoidance warning device. Consequently there is the need to distinguish device activation and provision of direction or type of hazard information simultaneously through visual displays, tactile displays or by manipulating the perceptive location or source direction of the warning. As a result, basic features of the auditory warning will always be present that will be uniquely reserved for imminent crash-avoidance warnings; however, localization cues within the “imminent“ crash-avoidance warning might be used to indicate the nature or location of the hazard. It is anticipated that this additional component will help to reduce the time required to respond effectively to the crash hazard (Tan and Lerner, 1995).

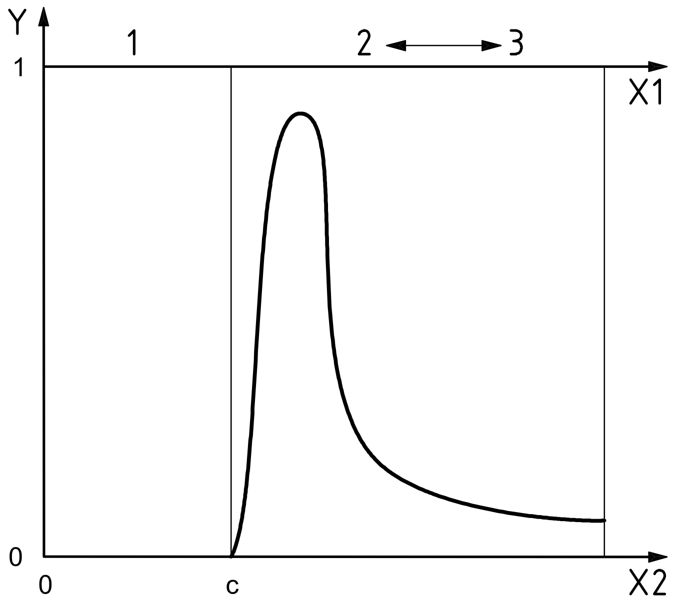
8.6 Other concepts

Horowitz and Dingus (1992) proposed four concepts to minimize the negative effects of a front-to-rear-end collision warning system:

- the graded sequence of warnings,
- the parallel change in modality,
- the individualization of warnings, and
- the headway display.

The graded sequence of warnings are warnings, from mild to severe, as a function of the time to collision, TTC. The longer TTC is, the milder the warning would be.

Figure 19 portrays the expected proportion of effective warnings as a function of the expected time to collision. “Effectiveness” is the probability that the warning might help the driver avoid an accident. An early mild warning will likely be effective in a small number of cases, but not startling. Assuming that the driver has already been alerted by milder warnings, a severe warning will likely not startle the driver and is thus effective.



Key

X1 warning severity
X2 time to collision
Y expected proportion of “effective” warnings

1 none (too late)
2 severe
3 mild

c critical point

Figure 19 — Expected proportion of “effective” warnings vs. time to collision (Horowitz and Dingus, 1992)

The parallel change in modality is a graded system from visual to auditory where visual signals provide milder warnings and auditory ones more severe warnings. Visual stimuli on the instrument panel or a Head-Up Display may serve as an alert to the auditory signal. In addition, a weak auditory signal can serve as an alert to a stronger auditory tone or speech signal.

The individualization of warnings is an approach where the driver is allowed to find his own tolerance level to mild and medium warnings. The driver can determine the desired warning frequency by turning a knob. For example, a young driver might only perform well with severe warnings because of his fast reaction time and possible lack of tolerance to frequent visual mild warnings, while a slower and more careful mature driver may tolerate mild visual warnings and therefore be assisted in coping with the more severe ones.

A headway display can provide the driver with feedback on his headway maintenance and assist the driver to maintain a safe headway, so that in case of an emergency, a mild warning rather than a severe one might suffice. The same headway display could be used for the visual part of an emergency collision warning display.

Terakubo *et al.* (1998) realized a solution for an optional warning presentation. The Automated Highway System (AHS) of Sumitomo Electric with lane-departure warning, crash-avoidance and incident-detection warning functions has a driver-system interface with a colour LCD monitor, where the navigation system is normally presented. It is changed as required to present information or warnings accompanied by audible alarms and announcements.

Basically, different modalities can be combined to get a powerful warning system, e.g. an alerting tonal signal with an informative visual message or an alerting tonal signal with an alerting and informative speech output. Depending on the urgency level, different combinations and designs were proposed. The synchronization and the coherence of the different single warnings have to be regarded. A master alerting signal which integrates the alerting cues of different warning systems has been proved to be a powerful tool in the avionics. The graded sequence of warnings are warnings from mild to severe, e.g. changing the modality. Assuming that the driver has already been alerted by milder warnings, a severe warning will likely not startle the driver and thus be effective.

9 Comparison of warning types, codes and modalities

The presentation of warnings can be differentiated into type of information, code of information and modality (Mutschler, 1985) (see Table 24).

Table 24 — Presentation of warnings (Mutschler, 1985)

Type of information	Code of information	Modality
Objects	Verbal	Visual
Spatial relations	Non-verbal	Auditory
Abstract information		Tactile

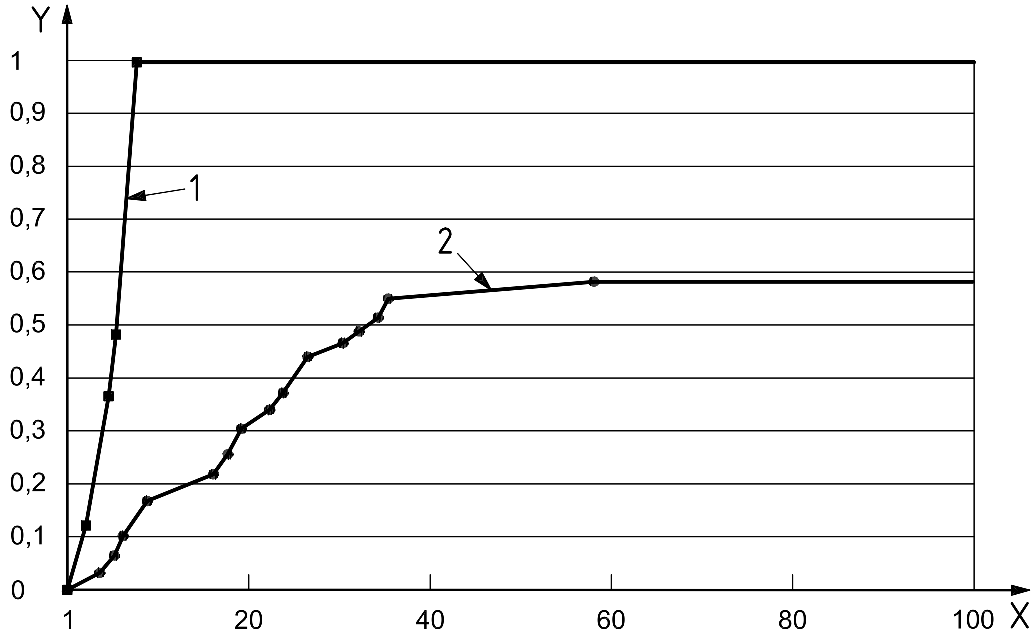
In the context of warnings, all those combinations are relevant. For example, the visual presentation of a non-verbally-coded object is an icon of the vehicle systems, such as a battery; the auditory presentation of verbally-coded spatial relations is speech output, e.g. about navigation information.

In the following subclauses, experimental comparisons of information presentation (including warnings) are categorized in this type-code-modality scheme.

Voss and Bouis (1979) conducted a series of experiments to compare the visual and auditory information presentation. The subjects had to control course and speed in a driving simulator and on a parking place. Speed limits and unexpected events (e.g. oil-pressure warning) were presented in different ways and had to be responded to by equivalent actions (e.g. by hooting). The change of the "useful field of vision" was measured by a specific pair of spectacles. Objective and subjective measurements were taken (e.g. reaction times).

9.1 Visual/auditory presentation of non-verbally-coded objects

The following diagram in Figure 20 shows the marked increase of the reaction time when an auditory signal [buzzer with S/R-difference of 9 dB (A-weighted)] was added to the visual one (oil-pressure warning) (Voss and Bouis, 1979). While all subjects reacted not later than 6 s after the onset of the combined visual/auditory alarm, 35 % of the subjects reacted to the pure visual signal later than 100 s.



Key

X reaction time, in seconds

Y cumulative frequency

1 acoustical/optical

2 optical

Figure 20 — Cumulative frequency of reaction times with auditory/visual (upper curve) and visual signal (lower curve) (Voss and Bouis, 1979)

The comparison between modalities depends on the warning intensity; intense light stimuli in the photopic range of vision are as effective as sounds in initiating fast reactions. At low to moderate sound-intensity levels, reaction times to auditory stimuli are approximately 20 ms to 30 ms faster then reaction times to visual stimuli (Boff and Lincoln, 1988).

Auditory presentations of non-verbally-coded objects are by far superior to visual ones concerning the reaction time of unexpected events. The comparison between modalities depends on the warning intensity.

9.2 Visual/auditory presentation of verbally-coded objects/abstract information

In other experiments, Voss and Bouis (1979) compared textual and spoken messages differing in length in a simple driving simulator (tracking) and a field experiment (see 5.3.2.2). The control error with auditory secondary stimuli is equal to baseline. With visual textual messages, however, it exceeds base-line by about 20 %. This holds true more or less for different message length.

The reaction to (visual) unexpected events (laboratory: lamp, field: braking lights of the preceding vehicle) is hardly influenced by speech output, but the reaction to an unexpected event while reading a visual message can have delays up to 3 s.

Campbell *et al.* (1997) investigated design alternatives for in-vehicle ATIS displays in driving simulators and in the field. Some key features of an ATIS system were included, e.g. check-in, platooning, and collision avoidance. The effect of display modality (auditory vs. visual), message style (command vs. notification), and display location (instrument panel vs. centre console) was examined in the experiment. Half of the messages were presented in the auditory/command style, e.g. “Slow Down” or “Change Lanes, “Pot-holes in Lane Ahead”, and half were presented in a visual/notification style, e.g. “Speed Limit 40 mph” or “Potholes in Lane Ahead”.

Their study in driving simulators showed that message style influences both compliance and safety. Command messages induce a high level of compliance with the message, but drivers tend to respond to command messages with less regard for other vehicles. Notification messages induced less compliance, but did not tend to degrade safety. Given the consequences for safety and compliance, command messages should be reserved for safety-critical situations. High criticality messages should use a command style, while low criticality messages should use a notification style with redundant roadway information.

The field test revealed that all of those receiving the auditory/command message slowed down, with a speed reduction with an average of 2,9 mph. All of those receiving the visual/notification message accelerated, with average increases in speed of 5,2 mph. Although all drivers complied with the message, it is interesting that the different message style had opposite effects on driver behaviour.

With visual textual messages more control errors are made compared to spoken messages. This holds more or less true for different message length. The reaction to an unexpected event while reading a visual message can have delays of up to 3 s. Drivers are more apt to follow instructions if presented in an auditory/command style than if presented in a visual/notification style. This tendency to obey the auditory/command message is so strong that drivers will comply even if the message is unnecessary or incorrect. Different message styles have quite different effects on driver behaviour.

9.3 Visual/auditory presentation of verbally-/non-verbally-coded spatial information

In another experiment Voss and Bouis (1979) investigated different coding of navigation information in a simple driving simulator: text and/or symbols (visual) output or speech (auditory) output. The route guidance messages included up to 4 instructions. Figure 21 shows examples with

a) text/one instruction,

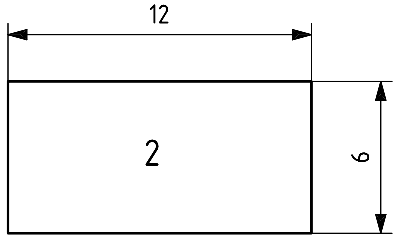
b) text/four instructions, and

c) symbol/four instructions.

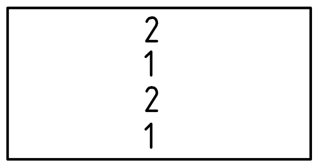
Glance duration increases with number of instructions for both visual modes. With one instruction, it is significantly longer for symbols than for text. There are two glances on the average, independent of the number of instructions.

Figure 22 shows the number of wrongly driven courses (a drive with at least one wrong direction decision) as a function of number of instructions and presentation mode. Driving errors increase with instruction complexity. Symbols are significantly better with two instructions. Speech output is worst with long messages of four direction instructions. Most of the subjects voted for a symbolic presentation, but several subjects recognized the longer interpretation process with symbols. Altogether symbols are the most appropriate presentation for guidance information.

Dimensions in centimetres



a) Route guidance message with one instruction

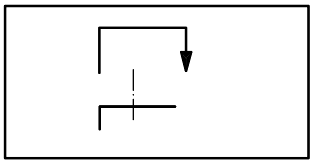


b) Route guidance message with four instructions

Key

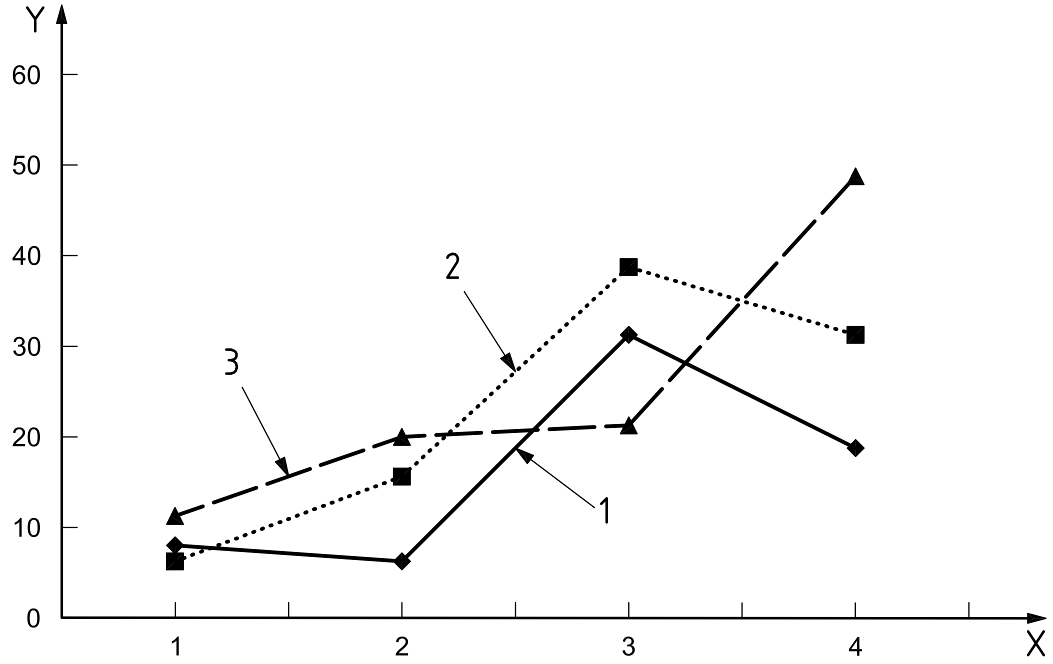
1 left

2 right



c) Route guidance by symbols with four instructions like b)

Figure 21 — Examples of the route guidance instructions (Voss and Bouis, 1979)



Key

X number of instructions

Y wrongly-driven courses, in percent

1 icons

2 text

3 acoustical

Figure 22 — Wrongly-driven courses (as a function of number of instructions and presentation mode, Voss and Bouis, 1979)

Vaughan *et al.* (1995) conducted an empirical road based user trial with Radio Data System Traffic Message Channel (RDS-TMC) within DRIVE II HARDIE program. The trial compared the presentation of information by auditory only and by both auditory and visual provision:

— Condition 1: Auditory only mode;

— Condition 2: Auditory and continuous visual mode;

— Condition 3: Auditory mode with visual display presented for 15 s.

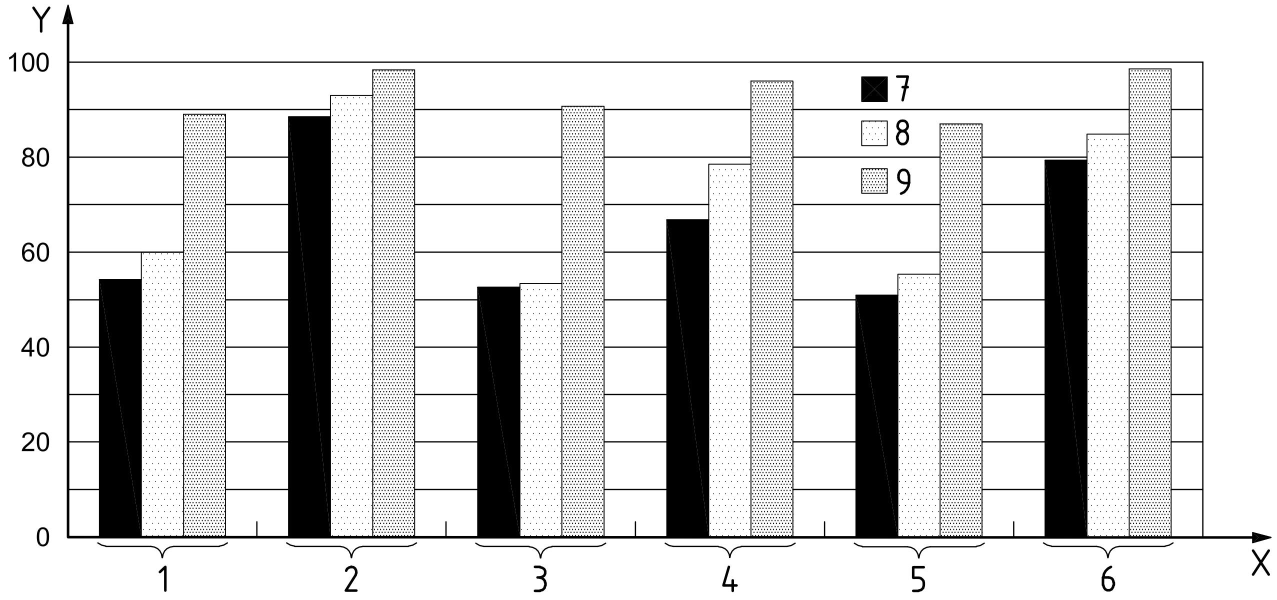
The driver was asked whether the message was relevant for the route that they were driving. If relevant, the driver was then prompted to repeat the elements present in the message. The subjective statements (NASA RTLX, comparative questionnaire) showed that condition 2 was preferred by nearly all subjects, because it most easily allowed information to be found. It took the least time (15 s) as compared to condition 3 (18 s) and condition 1 (22 s). Condition 1 was the most difficult and condition 3 distracted the driver most because they felt pressured to look at the message.

If visual and auditory presentations of differently-coded spatial information are compared, e.g. navigation information, users usually vote for a symbolic presentation. Speech output is worst with long messages of four direction instructions. Altogether symbols are the most appropriate presentation for guidance information. A combined auditory and continuous visual mode is better than an auditory mode only.

9.4 Visual presentation of non-verbally-coded information/auditory presentation of verbally-coded information

Within the framework of the Generic Intelligent Driver Support (GIDS) program, Verwey (1991) studied the spare information-processing capacity in various driving situations in order to develop an in-vehicle adaptive interface. Speech output (male recorded voice) and visual stimuli on the centre panel [19] were presented in an instrumented vehicle. Spare capacity was measured as the percentage correct responses on the secondary task, which consisted of reacting to those stimuli. The results showed that an added auditory task was clearly better performed than an added visual task, e.g. 95 %/77 % in a simple turn right and 85 %/54 % in a complex turn left (see Figure 23). The performance on the secondary tasks deteriorated differently in separate driving situations and an auditory addition deteriorated less in experienced drivers (not less than 95 % of the base-line performance) than in novice drivers (76 %).

19) The stimuli were not further specified in the paper.



Key

X driving situation

Y relative performance, in percent

1 merging/exiting
2 straight motorway
3 two lane roundabout
4 simple turn right
5 complex turn left
6 straight rural road
7 visual detection
8 visual addition
9 auditory addition

Figure 23 — Secondary task performance relative to baseline performance (Verwey, 1991)

While driving, speech (auditory verbally-coded information) is superior to visual stimuli (visual non-verbally-coded information) with respect to correct responses.

9.5 Visual/tactile presentation of non-verbally-coded objects/spatial information

Sklar and Sarter (1999) conducted an experiment in a flight simulator with 21 flight instructors to compare the effectiveness of visual and tactile cues for unexpected changes in the status of an automated cockpit system. Three experimental groups received

a) visual (label switching between “off” and “on”),

b) tactile (vibration of 250 Hz applied to the right wrist for 500 ms), and

c) redundant visual and tactile automation feedback.

Participants were wearing a wristband with one vibrator attached to each side of the wrist. Throughout the flight, participants had to monitor for unexpected mode transitions as well as traffic conflicts and deviations of an engine parameter and had to detect and identify the events. Two of the phases involved manual flight control, two flight phases were associated with automatic flight path control.

Results (see Figure 24 and Figure 25): Overall, both the tactile-only and the tactile-visual conditions led to higher detection rates and faster reaction times to uncommanded mode transitions (nearly 100%, ca. 1,5 s to 2 s) than visual feedback alone (ca. 70 % to 90 %, ca. 2,5 s to 5 s). Between the two tactile conditions, no significant difference in detection rates was found. This may be explained by the observed ceiling effect, i.e. detection performance of participants in the tactile-only condition was already perfect.

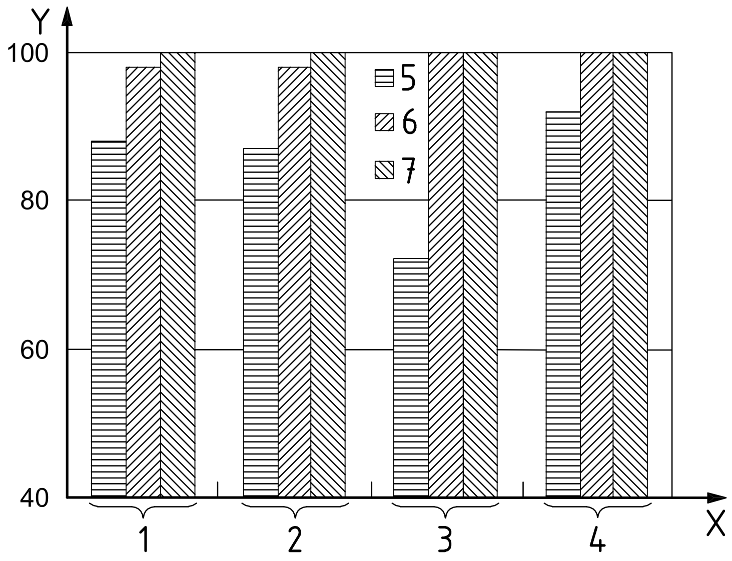
Similarly, overall reaction times to mode transitions did not differ significantly between the two tactile conditions. A more detailed analysis revealed, however, that pilots in the tactile-visual condition were significantly slower to respond in the presence of high concurrent visual load. This effect may be explained by the fact that reaction time in this study was a combined measure that included both the time until detection and the time until identification of the transition. Thus the reaction time of pilots in the tactile-only condition may have remained constant independent of concurrent task load because both detection and identification of a transition were performed based solely on the tactile cue and could be performed in parallel with other tasks. In contrast, pilots in the tactile-visual condition were required to direct or redirect their visual attention to flight mode annunciations on the primary flight display for identification purposes after they were alerted to the transition by the tactile cue.

The advantage of both tactile conditions over visual feedback is particularly pronounced under conditions of high concurrent load as present in the A/P Dynamic phase of flight. Whereas the detection of and reaction time to tactile cues in those conditions was not at all (tactile-only) or only minimally (tactile-visual) affected by concurrent visual demands, pilots who received only visual feedback showed a significant decline in their detection and reaction time performance. In the dynamic phase of auto-pilot flight, pilots had to perform a number of tasks that directed their visual attention away from the right-hand monitor where the mode transitions were indicated on the primary flight display.

Only two tactile cues were missed by pilots in the tactile-visual condition during manual phases of flight. Masking effects may have played a role, as both cues occurred while the stimulated hand was also actively manipulating the side-stick. Chapman *et al.* (1987) found decreased physiological sensitivity to tactile stimuli that are applied to an active part of the body. This masking effect may not have been observed in the tactile-only condition because those pilots were required to devote far more attention to tactile stimuli to be able not only to detect, but also to identify mode transitions. Thus, increased attention to the tactile stimuli may have counteracted their decreased physiological sensitivity to some extent.

The fact that a small number of transitions was missed in the tactile-visual but not in the tactile-only condition is somewhat surprising because the literature on cross-modal attention would lead us to expect enhanced detection performance in case of redundant cues. However, during the debriefing, pilots in the tactile-visual condition pointed out that they depended exclusively on the tactile stimuli to alert them to mode transitions; they did not monitor the visual cues.

One common element associated with all seven misidentified cues is that tactile feedback was presented to the outer wrist. Several participants in this experiment mentioned during the debriefing that signals to the outer wrist were perceived as being weaker than those to the inner wrist.

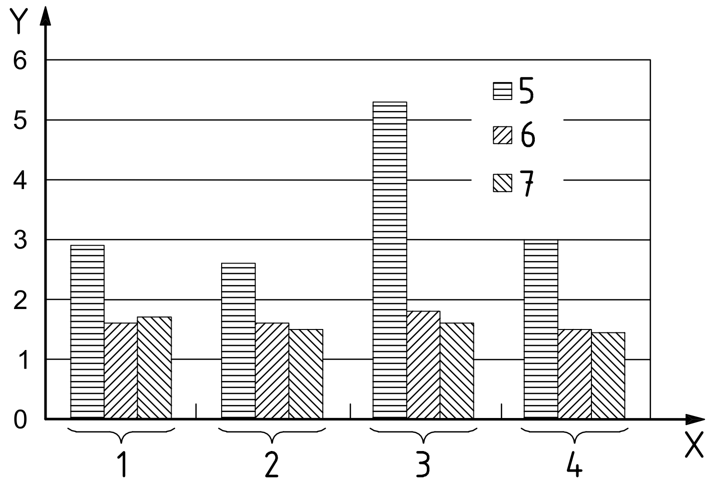


Key

X phase of flight
Y percent detected

1 manual flight detector on
2 manual flight detector off
3 autopilot dynamic
4 autopilot cruise
5 visual only
6 tactile-visual
7 tactile only

Figure 24 — Detection of mode transitions (Sklar and Sarter, 1999)



Key

X phase of flight
Y reaction time, in seconds

1 manual flight detector on
2 manual flight detector off
3 autopilot dynamic
4 autopilot cruise
5 visual only
6 tactile-visual
7 tactile only

Figure 25 — Reaction times to mode transitions (Sklar and Sarter, 1999)

In testing the effectiveness of visual, tactile, or tactile-visual combination interfaces for detection rates and response time, both the tactile and tactile/visual interfaces were found to be more effective than the visual alone condition. It was also found that the decreased sensitivity to tactile stimuli to an active part of the body (a masking effect) was more noticeable in the tactile-visual mode than in the tactile-only one. It was hypothesized this might be due to the subject's increased attention to tactile stimuli in the absence of visual ones. The subjects reported that stimulation to the outer wrist was perceived as much weaker than stimulation to the inner wrist.

9.6 Auditory/tactile presentation of non-verbally-coded objects/spatial information

Tactile displays are not currently widely used in automobiles. A work within the DRIVE project on Generic Intelligent Driver Support (GIDS) concentrated on active control devices, i.e. an active steering wheel and an active gas-pedal. Schumann (1994) attached a servomotor to the steering column, which can be used to influence the regular steering torque artificially to transmit proprioceptive-tactile cues to the driver which signal an affordance to react to the appropriate steering actions. Thus, the steering wheel conveys feedback concerning lateral control aspects to the driver and consequently serves also as a proprioceptive-tactile display. Since this torque change may lead to a startle reaction and over pull of the steering wheel, only small torque changes are employed. The increased intensity of the directional torque shift already causes a minor system-take-over [20].

20) Compare the study of Sato *et al.* (2001), p. 126.

In several experiments, parameters of the active steering wheel were investigated (Schumann, 1994). In a simulator experiment with different task demands, the proprioceptive-tactile warning signals via the steering wheel were studied while overtaking and driving in curves. When overtaking, the signal served as a warning signal to interrupt the overtaking manoeuvre (discrete proprioceptive-tactile warning signals). While during curve driving, the information should support the drivers' ability to drive safely through the curve (stabilization of the heading direction depending on the vehicle's lateral deviation from an optimal vehicle trajectory, discrete and continuous proprioceptive-tactile support).

As the results showed, there was no significant effect on lateral or longitudinal performance for the steering support strategy (discrete/continuous). There was, however, the tendency that the discrete proprioceptive-tactile warning signal via the steering wheel, as a rare event, had some negative effect on the quality of curve driving. The conclusion of the author is to employ a discrete proprioceptive-tactile warning only in the sense of redundancy gain together with visual information. The driver might not be willing to accept the calculated optimal trajectory.

For overtaking, two different discrete warning signals were used: an auditory and a proprioceptive-tactile warning. The trend showed a more likely reaction to the discrete proprioceptive-tactile warning signal. The vibration contains more specific information since this warning signal directly intervenes into the control behaviour of the driver. The subjects argued that they generally perceived the warning signals but that they still decided themselves to react according to a subjective judgement of the situation. The drivers found the vibration stimulus to be most unpleasant.

Basically, these results do not contradict those of Sato *et al.* (2001), see 7.1.

There is a tendency that a discrete proprioceptive-tactile warning signal via the steering wheel has some negative effect on the quality of curve driving. A discrete proprioceptive-tactile warning should only be considered in the sense of a redundancy gain together with visual information.

9.7 Visual/auditory/tactile presentation of verbally-coded objects/abstract information

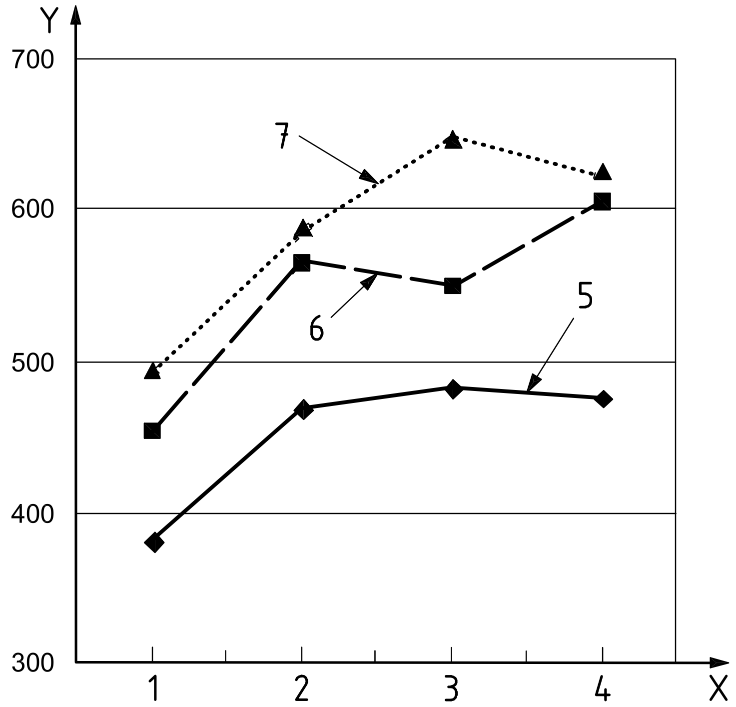
Johnston *et al.* (1972) performed an experiment with ten male college students to compare visual, auditory, and tactual warning devices under conditions of auditory and visual loading. The warning signals were a red light, a buzzer, and a vibro-tactile signal created by a piston on the skin vibrating at 800 cycles per minute. Upon detection of a signal, the subject responded by pressing the response button. The levels of loading were: no loading, auditory loading (letters of the alphabet with noise, subject had to call out the letter after "E"), visual loading (flashing three digit numbers, subject had to call out the numbers that ended in an even number), and combined auditory and visual loading. The dependent variable was the reaction time.

The results showed that the type of warning devices significantly affected reaction time. Differences existed between all three types of warning devices (see Figure 26). The tactile devices had the fastest reaction times under all loading conditions. The condition of loading also had a significant effect on reaction times. Loading of either auditory or visual channels slows the reaction to warnings in each channel considerably. The visual warning was affected by the visual loading more than by the auditory loading. The results of Johnston *et al.* (1972) indicate that a tactile warning device will function effectively as an attention-demanding signal. In comparison to visual and auditory warnings, the tactile device appears to affect a quicker reaction, especially under conditions of visual, auditory, or combined loading. Warning via the cutaneous sense is not intended to replace the visual and auditory senses, because the skin is not able to make fine discriminations or transmit complex information rapidly.

In comparison to visual and auditory warnings, tactile warnings of abstract information appear to affect a quicker reaction, especially under conditions of visual, auditory, or combined loading. Warning via the cutaneous sense should, however, not replace the visual and auditory senses, when complex information has to be transmitted rapidly.

9.8 Recommendations for warning systems

The following warning methods are recommended by Voss and Bouis(1979) on the basis of their experimental studies (see Table 25).



Key

X loading condition
Y reaction time, in milliseconds

1 no
2 auditory
3 visual
4 combined
5 tactual device
6 buzzer
7 light

Figure 26 — Reaction time vs. loading condition for tactual, visual, and auditory warning devices.

Table 25 — Recommended warning methods (Voss and Bouis, 1979)

Information	Frequency	Importance	Warning	Example
Binary	Seldom (e.g. 1×/year)	Important, time-critical	Immediate dynamic visual signal (blinking)	Oil pressure display
			Immediate dynamic visual signal (blinking) + tone (soft onset, increasing volume, synchron. intermittent)	
Binary	Seldom (e.g. 1×/year)	Not time-critical	e.g. in stationary vehicle	Brake lining
Verbally coded	—	—	Speech output with announcing tone	—
Spatial	—	—	Visual symbolic	Route guidance

Rarely-occurring binary alarms which are important and time critical, e.g. oil-pressure display, shall not be displayed as a conventional static signal but as a blinking lamp. Another possibility is to add to the blinking lamp a synchronously intermittent pleasant tone, which begins softly and increases in volume.

Alarms which are not time-critical, e.g. brake-lining display, should be given only in the stationary vehicle to prevent startling effects. All auditory alarms have to be designed carefully to prevent this effect.

Verbally-coded messages comprising several words should be presented as speech output.

Spatial navigation instructions should be given in symbolic form. If they are given in the form of a verbal code, they should include as few instructions as possible.

Concluding Clause 9, the comparison of different warning modes becomes more detailed if type and code of information, as well as sensorial modality are taken into account. Voss and Bouis (1979) conducted a series of experiments in a driving simulator and on-road with relevant results for the design of warning modes. When non-verbally-coded objects have to be detected as a secondary task, subjects react much earlier to a combined visual/auditory alarm than to a auditory-only one. Concerning verbally-coded objects, the control error with spoken messages is clearly less than with visual textual messages. Text is better suited for spatial information, like navigation information, if just one instruction is given; and symbols are better if two or more instructions are presented. Speech output is the worst. If the code is adapted to the modality, i.e., verbal code for auditory information, added tasks are clearly performed better with speech output. For spatial information which has to be reacted upon immediately during driving, the auditory and tactile channels are preferred. However, it is still not conclusive if one of those channels is the better one.

10 Warnings in assistance systems

Assistance systems are systems that help the driver to conduct his driving tasks. ISO/TC 204/WG 14 is establishing standards for systems that avoid accidents, increase roadway efficiency, contribute to driver convenience and reduce driver workload (Komoda and Goudy, 1995).

Systems that assist with any of the following are standardized:

— avoiding crashes;

— increasing roadway efficiency;

— adding to driver convenience;

— reducing driver workload;

— improving the level of traveller safety, security and assistance.

As are systems that use information about the driving environment to perform any one or more of the following functions:

— monitor the driving situation;

— warn of impending danger;

— advise on corrective actions;

— partially or fully automate driving tasks;

— report traveller distress and request required emergency services.

Assistance systems need a high level of interaction with the driver, such that a human-centred design is necessary (Johannsen, 2000). One of the main aspects in assistance systems is the presentation of information. The information can be categorized (Johannsen, 2000) as

- warnings,
- error messages,
- state information,
- intention declarations, and
- instructions for actions.

A decisive criterion for assistance systems from a legal perspective is the degree of intervention permitted by the system with regard to deciding how the vehicle is driven. This is especially relevant to liability. Differentiation is therefore made between three classes of intelligent assistance systems (Stevens, 2001).

a) Information on the traffic situation is evaluated by the system and leads to a suggestion or warning addressed by the system to the driver.

b) Information on the traffic situation is evaluated by the system, which makes a decision on how to drive the vehicle. The driver has the possibility of overriding that decision.

c) Information on the traffic situation is evaluated by the system, which makes a binding decision on how the vehicle is driven, leaving the driver no opportunity to override that decision.

If the driver’s tasks are used as criterion, driver-assistance systems can be categorized as follows (Metzler, 1992; Komoda and Goudy, 1995). There are systems for:

- **Primary driving tasks:**
  - distance control;
  - speed control;
  - adaptive cruise control systems (ACC);
  - Mayday systems;
  - electronic stability program (ESP);
  - lane-departure warning system(LDW);
  - forward-/side-obstacle warning system;
  - short range obstacle warning system;
  - roadside traffic impediment warning systems;
  - “stop & go” automation;
  - indirect vision, electronic eye;
  - blind curve and intersection;
  - warning systems;
  - curve forecast.

— **Navigation:**

  — navigation systems;

  — congestion avoidance.

— **Travel preparation:**

  — economy;

  — comfort.

A further classification is established by ISO/TC 204/WG 14, e.g. for obstacle warnings (see Table 26).

Table 26 — Classification, e.g. for obstacle warnings, established by ISO/TC 204/WG 14

Object	Location/type	
Obstacle	Front	Visible Visually obstructed
	Side Rear Multi-directional	 Visible Visually obstructed Obstructed
Etc.		

All legal analyses and all topics concerning user-friendliness of the products concerned show that certain basic requirements have to be met by the systems including the system warnings (Stevens, 2001):

— reliability over time and with regard to external influences;

— robustness in case of a system malfunction or misuse;

— perceptibility of the human machine interface;

— comprehensibility;

— predictability of system functionality, controllability in every situation.

ISO TC 204/WG 14 is establishing standards for a wide range of driver-assistance systems, which are designed to aid the driver and improve the efficiency and safety of the surface transportation system. As these assistance systems require a high level of interaction with the driver, a main aspect of which is the presentation of information, human-centred design is essential.

Legal liability may arise from the degree of vehicle control permitted by the system. Whether the driver-assistance system does or does not take control of vehicle dynamics, and whether or not that control may be overridden by the driver, are all design decisions that carry liability implications.

While there are many ways to classify such systems, certain basic requirements must be met relative to their robustness, perceptibility, comprehensibility, predictability and controllability.

10.1 Distance warning systems

Systems for warning of insufficient headway to the preceding vehicle (or keeping a safe distance automatically) contribute to driving safety and comfort (Metzler, 1992). The main problem is the warning strategy, which is more important than the actual warning method. If warnings are given too frequently or too rarely, the acceptance of these systems by the drivers decreases. An experimental study with different warning strategies for a distance warning system showed that the acceptance depended on the warning strategies and warning duration (Leutzbach *et al.*, 1980). There is a balance between driving safety, driving comfort and traffic efficiency.

Distance warning systems need different warning strategies depending on actual driver state, situation and driving motivation. To develop driver-adapting systems is a future objective (Metzler, 1992). For distance warning systems, different warning methods were studied and proposed (Köhler, 1974; Metzler, 1992). Visual, auditory and tactile displays are proposed. The visual displays have different levels from pure lamp signals to analogous scales.

— **Visual warnings**:

To differentiate between risk and danger, a round segment scale of 200° was investigated (Metzler, 1992). The green part represented a low risk; the yellow part stood for acceptable risk (relatively safe distance) with optimal driving according to risk and efficiency. The red range represents a high risk, which should be reduced by braking.

A visual distance warning system used a head-up display where a bright beam was projected onto the street to indicate the critical distance to the preceding vehicle (Assmann, 1987).

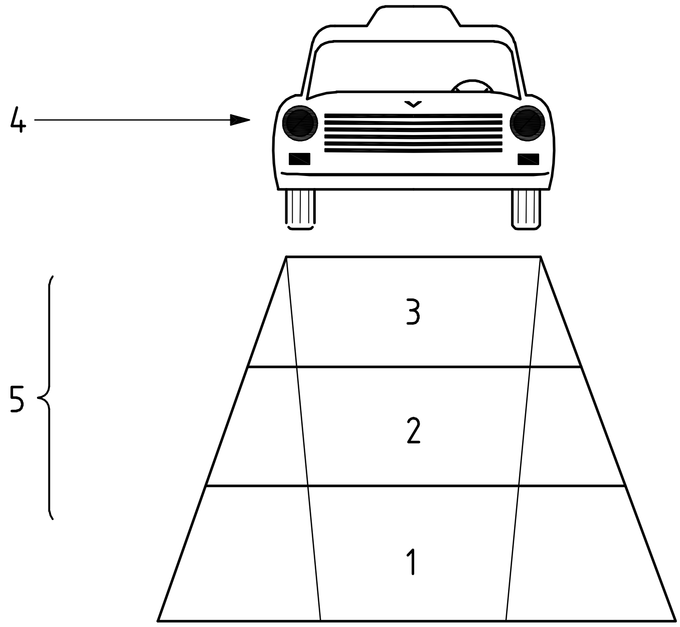
— **Auditory warnings**:

An auditory solution for a distance warning system is proposed as an intermittent tone sequence where the frequency increases with reduced distance ending in a permanent tone (Wüchner and Reiniger, 1978).

An even more sophisticated acoustic system was proposed by Reiniger and Wüchner (1979). The frequency of the warning tone was deduced from the distance and relative speed between vehicles. Driving in columns below safety distance resulted in a warning tone of about 1 kHz; a fast approach to slow or standing vehicles resulted in a warning tone of about 1,6 kHz. Additionally the repeating frequency of the intermittent tone signal was adapted to the danger level, i.e. a faster repetition with decreasing distance. The volume depended on the subject vehicle speed to overcome the vehicle noise.

— **Visual/auditory warnings**:

One realization was to present the distance directly in metres together with a warning lamp (yellow/red), which signalizes insufficient headway for safety. An option for a parallel auditory warning parallel to the red light was proposed. The idea was to initiate a higher attention level and a shorter reaction time. (Efficiency results were not reported.) Another distance warning system also used a combined visual and auditory warning (Ackermann und Wocher, 1980) (see Figure 27). On a simplified road scene three different areas relating to different danger levels were displayed green, yellow and red by LED or LCD.



Key

1 green
2 yellow
3 red
4 function
5 distance

Figure 27 — Proposal for a distance warning display (Ackermann and Wocher, 1980)

10.2 Collision warning systems

There are a number of systems for longitudinal support/control, which are either in development or have been realized. These include: Adaptive cruise Control (ACC), Anti-Collision Systems, collision warning, Emergency Intervention, Detection of Vulnerable Road Users, ACC with Stop & Go extension, Telematic Speed Recommendations/Speed adjust, Intelligent Speed Adaptation (ISA), Geographical Pre-Information and Longitudinal Support (Stevens, 2001). Of these, the collision warning systems are discussed further, to demonstrate the possible warning methods [21)].

The main purpose of collision-avoidance (or crash-avoidance) warnings is to alert the driver to a hazardous situation requiring some action to avoid a collision. In addition, the warning may serve to educate the driver by providing feedback concerning desirable practices or unsafe acts (Lerner *et al.*, 1996). A collision-avoidance device should be capable of generating at least two levels of warning: imminent and cautionary crash-avoidance warnings, differing in urgency.

Mortimer (1988) classified rear-end crashes in two categories: Coupled and uncoupled vehicles. A coupled pair of vehicles refers to a situation where a change in speed of the lead vehicle is mimicked by the driver of the following vehicle. Vehicles are not coupled when following distances are initially sufficiently great that speed variations of the lead vehicle are not perceived to be of immediate consequence to the driver of a following vehicle. The same warning design principle may apply in coupled and uncoupled cases: A graded warning system (see 8.6), from mild to severe, according to the time left until action is required for avoiding a crash.

21) The collision warning devices again can be categorized into blind spot and backup warnings (encroachment or crossing path) devices (Lerner *et al.*, 1996).

Collision-avoidance systems “promise” to provide the driver with timely information about the potential for imminent collision (Hancock and Parasuraman, 1992). They can react to situations that humans can not or do not cope with (Seller *et al.*, 1998). Collision-warning/collision-avoidance systems (CW/AW) include algorithms that specify nominal criteria for warning and braking. Warnings given by the system should result in a minimum load on driver attention. An increase in warning frequency produces a trade-off between two harmful driver responses. Frequent warnings may desensitize the driver and cause future warnings to be ignored. Rare warnings can distract the driver during critical situations. One potential solution for a careful warning design is to provide the driver constant visual feedback. Graduated light displays or relative distance displays may not be obtrusive to the driver. Desensitization and startling can be avoided.

In an on-road experiment Dingus *et al.* (1997) investigated the effect of false collision alarms on drivers' following behaviour [22]. The collision-avoidance display was the combination of visual bars display with auditory warning (see below). There were four percentages of false alarms: 0 %, 25 %, 50 %, and 75 %. For example, in the 75 % category one true alarm corresponded to three false alarms. Younger drivers tended to drive closer to the lead vehicle. However, as the number of false alarms increased, they were more likely to increase their following distance. Once the percentage of false alarms exceeded 60%, younger drivers decreases their head-ways, indicating that they may have lost trust in the system.

Belz *et al.* (1999) examined different warning modes (presentation mode) for front-to-rear collision avoidance in a simulator-based study [23]. The participants were 24 men who were licensed commercial truck drivers (age range 19 years to 51 years, mean age of 31 years). Beside presentation mode, vehicle speed and vehicle headway were used as independent variables. The measures were initial response time (releasing the accelerator or making a steering correction) and the overall brake response time.

The display presentation modes were:

— no display

— dash-mounted visual display: red trapezoid warning indicator flashing intermittently at a rate of 2 Hz to 4 Hz,

— auditory icon only: sound of a tyre skidding [24],

— conventional auditory warning (four pure tones at 500, 1000, 2000, and 3000 Hz presented concurrently during one pulse of 0,35 s [25]),

— mixed modality 1 (auditory icon and visual display),

— mixed modality 2 (conventional auditory warning and visual display).

The dash-mounted visual display resulted in significantly longer initial response times than did those with any other display (see Figure 28). This was not surprising since it was outside the driver's direct field of view and the auditory warnings are of an omnidirectional nature. The auditory icon was found to elicit significantly faster brake response times than did the conventional auditory warning (difference 122 ms) or the no-display condition (difference 96 ms). This was attributed to the reduced cognitive processing times with auditory icons.

No significant differences were found between the conventional auditory warning and no-display conditions, which was not expected. This was interpreted with the necessity of an additional time which is required to cognitively process the warning signal, recall its meaning and initiate a response.

22) Lerner *et al*. (1996) differentiate between “false warnings” which are triggered by an inappropriate stimulus event (e.g. rain) and “nuisance warnings” which are triggered by an appropriate stimulus event under conditions which are not useful to the driver (e.g. obstacles along the roadway).

23) A similar experiment was conducted for side collision avoidance, described in 10.3.

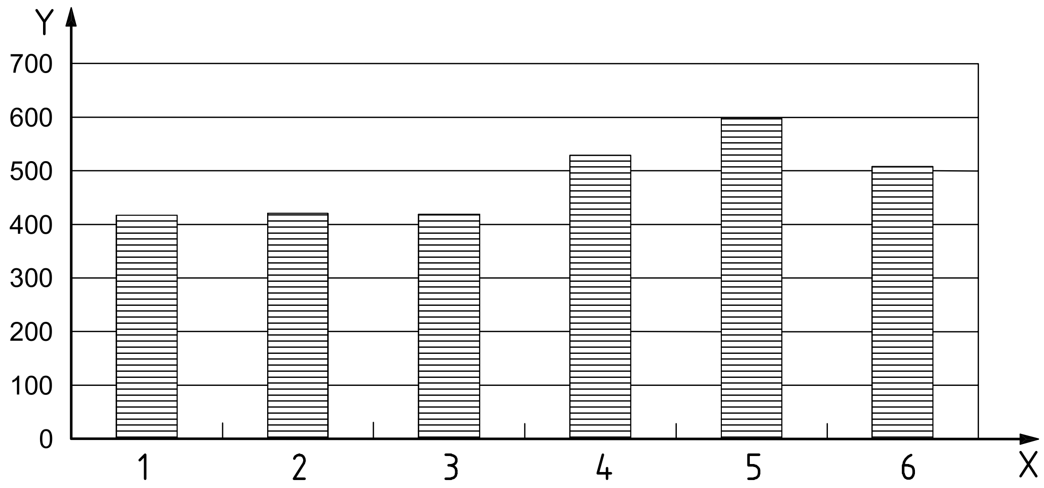
24) 13 dB above masked threshold values in at least one one-third-octave band (ISO 7731)

25) 13 dB above masked threshold values in at least one one-third-octave band (ISO 7731)

Both multimodal displays were found to elicit response times that were significantly faster than those with only the dash-mounted visual display. This was expected and may be attributed to the fact that the multimodal displays contain the omnidirectional attribute of the auditory displays. The combined visual display/conventional auditory warning led to significantly faster initial response times than the conventional auditory warning alone. One possible explanation for this result is that on hearing the conventional auditory warning signal, participants had to interpret the signal, which involved some uncertainty. The addition of a visual display reduced this uncertainty. The presentation of the auditory signal alerted the driver that "something is happening" and the visual display provided more specific information as to what has happened.

No objective differences were found between the multimodal display and the auditory icon alone. By its very nature, the auditory icon is already representative ("the image is built in"). Half of the participants, however, were sceptical of the auditory icons, indicating that they did not sound like "serious" warning signals.

The subjects preferred the combined auditory (conventional or auditory icons) and dash-mounted visual display.



Key

X display mode

Y initial brake response time, in milliseconds

1 visual and auditory icon

2 visual and auditory tone

3 auditory icon

4 auditory tone

5 visual

6 no display

Figure 28 — Display type effect for initial brake response time (Belz *et al.*, 1999)

About one-half of the participants were able to correctly identify the meaning of the conventional auditory warning signals (near to guessing probability), whereas 96 % of them correctly identified the auditory icons. The authors conclude that if a driver is unable to distinguish between two conventional warning sounds, he may ignore them completely and the warning devices become of questionable use. This, however, is contradictory to the basic ability of distinguishing between about 10 sounds coded in different dimensions (see 6.3.6.1).

Dingus *et al.* (1997) conducted three on-road studies to determine how headway maintenance and collision warning displays influence driver behaviour. The objective of Experiment 1 was to determine the most adequate visual display for maintenance/collision warning. 108 persons of three different age groups participated. A 5-inch × 7-inch colour LCD screen mounted in the dashboard next to an analogue speedometer was used. The display variants are listed below.

— **Perspective vehicle icons**: Dynamic vehicle icons moving along a multicoloured perspective roadway. As the distance between the participant vehicle and the lead vehicle decreased, the distance between the vehicle icons on the display decreased and vehicle icon on the display increased. When the headway reached a critical point, the display flashed at 4 Hz.

— **Perspective bars**: A series of nine coloured bars placed in perspective. As the distance between the participant vehicle and the lead vehicle decreased new bars were displayed one below another, decreasing in number and changing from green (headway > 1,6 s) to orange (headway 1,1 s to 1,6 s) and then to red (headway < 0,9 s to 1,1 s, flashing on and off at a rate of 4 Hz).

— **Blinking block display**: A blinking block display served as control condition

Different scenarios were included: Coupled headway, fake brake, coasting deceleration, fake turn, moderate brake, normal brake, i.e. headway and brake conditions were considered. The participants were asked to perform certain distracter tasks.

Concerning the headway condition, the vehicle icon display induced significantly longer headways (about 0,2 s) than did the bars display or the blocks display. Only the vehicle icon display produced significantly longer headway distances than its associated baseline condition.

Concerning the braking conditions, the mean headway was not found to be significantly different between the displays. However, both the bars display (0,4 s longer) and the vehicle icon display were shown to be significantly different from their associated baseline. Moreover, the bar and icon displays resulted in fewer short headways during braking events.

The main objective of Experiment 2 of Dingus *et al.* (1997) was to determine the most appropriate sensory modality for presenting collision-warning information. Sixteen young persons participated in the experiment with following display conditions:

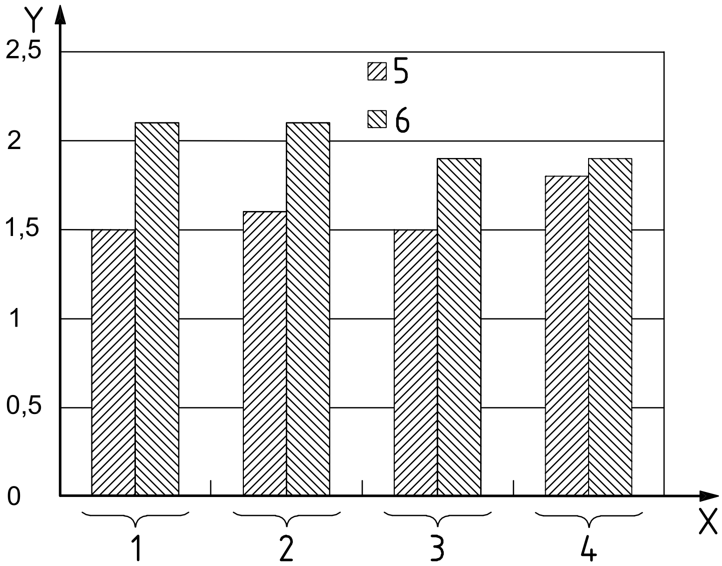
a) visual only (bars display of Experiment 1);

b) auditory only (digitized voice differing in urgency until "Look ahead" and "Brake");

c) visual and auditory;

d) digital headway display.

There were no significant differences between the interesting conditions a) to c) (see Figure 29). The visual and the combined visual/auditory presentations, however, produced significant increases in following distance for the coupled headway events. The distances increased from 1,5 s to 2,1 s (visual display), from 1,6 s to 2,1 s (combined display), and from 1,5 s to 1,9 s (auditory, not significant). Also, for events that involved deceleration of the lead vehicle, minimum headway increased significantly for all systems when compared with their baseline drive.



Key

X display condition

Y mean headway, in seconds

1 visual only

2 visual/auditory

3 auditory only

4 digital

5 digital speedometer

6 collision warning display

Figure 29 — Display condition effect on headway for coupled headway events (Dingus *et al.*, 1997)

There is preliminary evidence that auditory icons, or representational sounds, may be useful as warning devices in vehicles. If the users, however, remain sceptical, a dual-modality display utilising conventional auditory warnings and a dashboard-mounted visual display might be the best solution for front-to-rear collision-avoidance warnings.

The perspective displays help participants to maintain larger, safer headway distances during both coupled headway and braking events than when they drove without any display at all.

The combination visual/auditory display had the greatest impact on maintaining larger, safer headway distances. It helped to increase them significantly both when the drivers were coupled with another vehicle, and during braking events.

Extensive human factors guidelines for Crash-Avoidance Warning Devices are given by Lerner *et al.* (1996). They are incorporated in Table 27 or elsewhere in the present report.

Table 27 — Human factors guidelines for Crash-Avoidance Warning Devices are given by Lerner *et al.* (1996)

Recommendations	Explications
Imminent crash-avoidance warnings must be presented in at least two modes: visual and auditory or tactile.	Since imminent crash-avoidance warnings are of highest priority, redundancy is critical.
Auditory displays are the recommended mode for imminent crash-avoidance warnings.	The auditory display should be distinctive and reserved only for crash-avoidance warnings.
Cautionary crash-avoidance warnings should be presented visually or by means of (less intrusive) auditory or tactile signals.	Cautionary crash-avoidance warnings are less urgent but still time-critical.
Multiple imminent crash-avoidance warnings should be automatically prioritized in terms of their severity and urgency.	Only the highest priority crash warning should be presented in the auditory or tactile modality.
Warnings should be presented in a manner that is compatible with the driver's desired vehicle control response.	The warning should induce an orienting response, causing the driver to look in the direction of the hazard.
Auditory warnings:	
Warnings should locate the sound source such that the warning appears to emanate from the position which is closest to the target location.	Auditory warnings can be used to provide directional information because humans are very good sound localizers.
Auditory warnings that are presented to the front or rear of the driver should not be presented in the median plane.	Humans have difficulty identifying sounds directly above, in front of, or behind them, without some head movement.
Intensity and duration coding not recommended.	Humans are poor judges of absolute intensity and duration levels.
Fundamental frequencies: 500 Hz to 3 000 Hz.	see 6.3.4.1
Acoustic warning intensity: at least 20 dB, but no more than 30 dB above the masked threshold.	see 6.3.4.2

Some definitions of abbreviations describing Forward Collision Systems are given in the SAE J2400 Information Report. Examples are shown in Table 28.

Table 28 — Definitions of abbreviations describing Forward Collision Systems (SAE J2400 Information Report)

FCW	Forward Collision System
Lead vehicle (LV)	A vehicle in the path of the subject vehicle that presents a potential threat of collision.
Subject vehicle	The FCW-equipped vehicle under consideration.
Alert zone	The alert zone defines which vehicles in front of the subject vehicle are allowed to trigger FCW alerts.
Brake system lag	Time interval between when the brake pedal is pressed and when the vehicle begins to decelerate.
etc.	

In addition, several operating characteristics are enumerated in the Information Report SAE J2400 (see Table 29 and Table 30).

Table 29 — System and information display characteristics — Examples

Minimum operating speed	The minimum speed at which the system is active should be no greater than 40 kph.
Built-in diagnostic testing	All FCW devices shall include built-in diagnostic testing to verify that the device is capable of operating within specified performance limits.
Automatic termination of warnings	The device that triggers a warning should terminate the warning automatically once the triggering condition no longer exists or an appropriate driver response is initiated.
etc.	

Table 30 — Requirements for the occurrence of crash alerts (examples)

Geometric characteristics of the alert zone	An alert zone defines which vehicles in the subject vehicle's path are allowed to trigger FCW imminent alerts.
Computing alert time requirements	To compute crash alert timing requirements the range at which the FCW system's imminent alert begins must be observed.
etc.	

Performance evaluation test methods

The performance evaluation tests described are scripted manoeuvres that are strictly intended to be executed in a proving ground or closed-course setting. In this test, two different kinds of manoeuvres are simulated. These kinds are called rear-end crash and out-of-path nuisance.

Crash alert tests are, for example,

— SV (subject vehicle) at 100 kph approaches stopped vehicle,

— SV (normally at 60 kph) approaches 10 kph principal other LV (lead vehicle),

— SV at 100 kph, principal other LV braking moderately hard from same initial speed,

— etc.

Out-of-path nuisance alert tests are, for example,

— SV 100 kph passes between trucks travelling at 3kph in adjacent lanes,

— SV at 100 kph approaches overpass,

— etc.

10.3 Side-obstacle warning systems

There are a number of systems for lateral support/control, which are in development or have been realized (McGehee, LeBlanc, Kiefer, Salinger, 2002).

EXAMPLE Heading control (HC), lane-change Support, lane-departure warning support (LDW), autonomous lateral control, side-obstacle warning systems (SOW).

The aspects of warning of the side-obstacle and the lane-departure warning systems are further discussed in 10.3 and 10.4.

The Standardization Working Draft for PWI 14.5 (PWI 14.5) specifies system requirements and test methods for side-obstacle warning systems (SOW) including the requirements for the associated MMI. Side-obstacle warning systems are fundamentally intended to warn the driver of the subject vehicle of potential collisions with objects to the side of the subject vehicle during lane change manoeuvres. A side-obstacle warning system is intended to supplement the interior and exterior rear-view mirrors, not eliminate the need for such mirrors.

The system is intended to detect vehicles to the rear and sides of the subject vehicle. When the subject vehicle driver indicates the desire to make a lane change, the system will evaluate the situation and warn the driver if a lane change is not recommended. The system will not take any automatic action to prevent possible collisions. Responsibility for the safe operation of the vehicle remains with the driver.

The Working Draft defines vehicles (subject, target), zones (coverage, adjacent, etc.), clearances and lines around the subject vehicle (A, B, C, etc). SOW systems are classified in 10 types including different coverage zones and one or more functions from blind spot warning, closing vehicle warning and lane change warning. For example, type I covers the left adjacent zone and can be referred to as blind spot warning system.

A SOW system can be active or inactive. In the active state it provides a warning if the warning requirements are fulfilled (warning state), otherwise it does not warn (non-warning state). The side-obstacle warning system may be activated based on the subject vehicle turn signal status, the subject vehicle speed, the steering input, on the vehicle's position/motion or manually. A visual system active indication may be used to indicate to the subject vehicle driver that the SOW system is functional. A system warning shall indicate to the subject vehicle driver that a lane change manoeuvre will result in a threatening situation. At a minimum, the system warning indication shall consist of one of the following: a visual, an audible, or a tactile warning. For SOW systems that are activated continuously the system warning indication shall be visual-only. Visual warnings should in some way indicate the side on which the threat is present. It is recommended that visual warning indicators should be placed in locations that will encourage mirror usage. The SOW system may augment the visual warning with audible and/or tactile warnings. If an audible or tactile warning is used, it should be clearly distinguishable from other audible or tactile signals in the vehicle.

The standard must consider conditions under which a blind spot warning system must not give a warning. These conditions are intended to reduce unnecessary warnings and thereby promote driver acceptance of these systems. A participant of WG 14 feared that warnings would be generated quite often and audible or tactile warnings would be a nuisance to the driver and present a barrier to driver acceptance. He suggested the warning should be visual-only in order to obtain driver acceptance.

Belz *et al.* (1999) examined different warning modes (presentation modes) for side collision avoidance in a simulator-based study [26)]. The scenarios depicted vehicles alongside the tractor-trailer. Beside presentation mode vehicle speed, mirrors (present, not present) and workload were used as independent variables. The occurrence of accidents was used as the measure.

The display presentation modes were similar to the Collision-Avoidance Warning System (see 10.2):

a) No display;

b) Dash-mounted visual display;

c) Auditory icon only: sound of a long horn honk [27)];

d) Conventional auditory warning: 500 Hz pure-tone carrier with a positive saw-tooth function frequency-modulated over a 0,35 s pulse [28)];

e) Mixed modality 1 (auditory icon and visual display);

f) Mixed modality 2 (conventional auditory warning and visual display).

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26) A similar experiment was conducted for front-to-rear collision avoidance, described in 10.2.

27) 13 dB above masked threshold values in at least one one-third-octave band (ISO 7731)

28) 13 dB above masked threshold values in at least one one-third-octave band (ISO 7731)

Participants had significantly fewer collisions when the auditory icon, as opposed to a conventional auditory warning, was used. This was attributed to the high salience and identification of the auditory icon. This held true especially with the addition of the visual display. (The use of warning stimuli from complementary symbolic subsystems resulted in improved operator performance).

The subjects preferred the combined auditory (conventional or auditory icons) and dash-mounted visual display.

The Standardization Working Draft for PWI 14.5 specifies detailed system requirements and test methods for side-obstacle warning systems (SOW) including the requirements for the associated MMI. At a minimum, the system warning indication shall consist of one of the following: a visual, audible, or tactile warning. One problem as to driver acceptance could be frequent audible or tactile warnings. Detection of side-wards obstacles is better with auditory SOW signals, with or without a visual display. Subjects, however, also accept dash-mounted visual displays.

10.4 Lane-departure warning systems

Lane-Departure Warning Systems (LDWS) are based on a fundamental traffic rule of “lane keeping”, or driving within the lane. Departing from the lane could lead to a run-off-road crash and could endanger the safety of following or on-coming vehicles in the adjacent lane. An LDWS warns the driver and urges him to take a preventive operation to stay within the lane.

One such system is the Mitsubishi Driver Support System[29)] launched on the Japan's market in 2000 (Motoyama *et al.*, 2001). The system warns the driver with visual and sound messages, plus steering wheel vibration. Moreover, the system generates an additional steering torque (see Clause 7). Investigations led to the following result:

LDWS needs an appropriate prediction time in order to issue a warning in time to allow the driver to take corrective steering operation. If the prediction time is long, the driver can easily avoid a lane departure but may be bothered with too frequent warnings.

Time to departure (TD) is defined as the time any part of the vehicle body crosses the lane marking, and is calculated from lane recognition, vehicle speed and yaw rate. An on-road experiment revealed that TD lower than 1,5 s is very rare in the actual traffic conditions. This means that a prediction time longer than 1,5 s may annoy the driver. As a result the prediction time of 1,0 s was selected as the default value, which minifies the nuisance alarm without affecting the efficiency (Motoyama *et al.*, 2001; Suzuki *et al.*, 2001).

The frequency of warning output is defined as:

frequency of warning output = [total time of the warning output/duration of the (experimental) trip] × 100

When the warning timing is set at 2 s, then a warning frequency of 2 % results (Suzuki *et al.*, 2001).

Seven experienced drivers evaluated the practicality of the LDWS on an inter-city expressway (Motoyama *et al.*, 2001). The system warned 34 times during the experiment. The subjective rating was 68 % of the total warnings were “useful” or “a little useful”. This subjective rating 68 % could be high, for drivers generally have a tendency to feel annoyed with warnings.

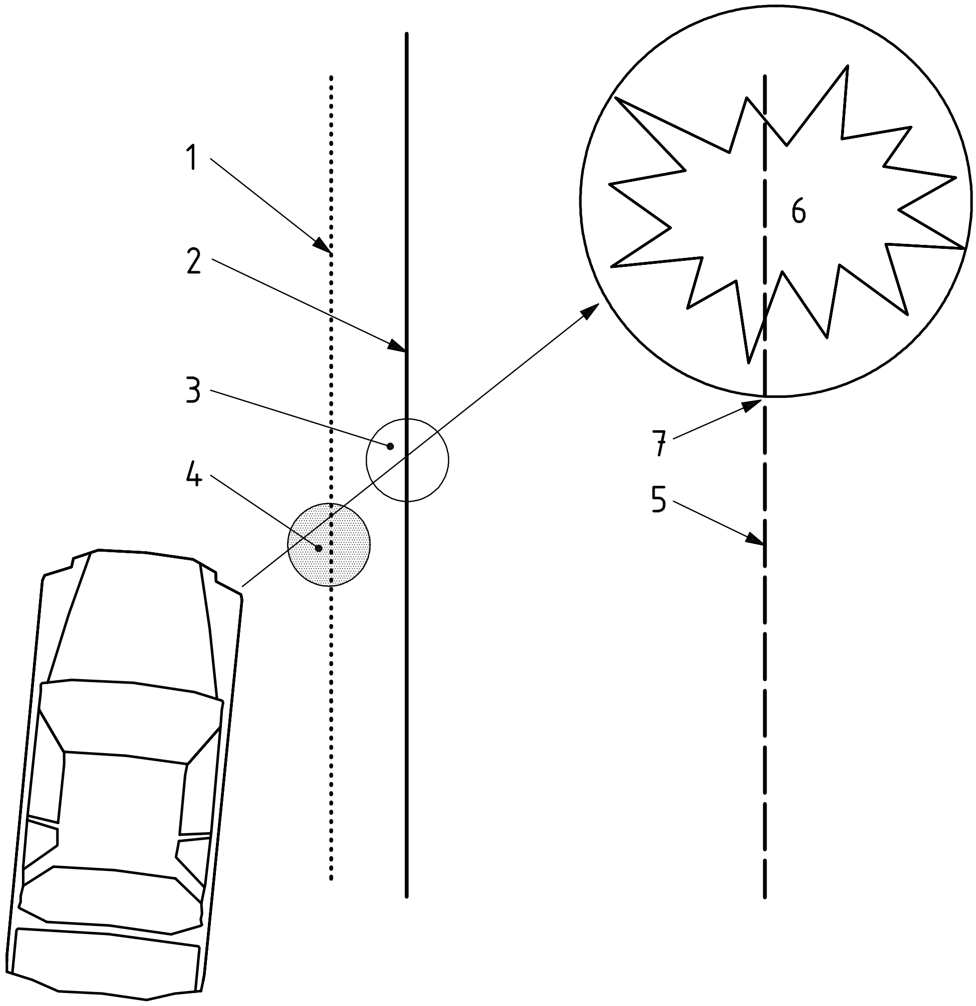
Research results have proven that a warning through the steering wheel is very effective when combined with an auditory warning (Motoyama *et al.*, 2001). The addition of the steering wheel vibration to an auditory warning significantly shortens the driver’s response time to initiate a corrective steering operation (see Clause 7). Application of a steering torque as the information toward the lane centre further reduces the response time. The torque also tells the driver how he should react. Consequently, it was decided to use the combination of all three warning methods.

29) Mitsubishi Driver Support System is an example of a suitable product available commercially. This information is given for the convenience of users of this Technical Report and does not constitute an endorsement by ISO of this product.

In the lane-keeping and turning assistant of VW, a combined visual/auditory warning is envisioned (Anders *et al.*, 2000). A red warning triangle is activated in the outside mirrors when a target object approaches the subject vehicle at a distance of less than 20 m. If the object is moving to the lane limitations of the subject vehicle, or the indicator is turned on, then an additional auditory signal is set. This HMI is claimed to be intuitive, intelligible, not distracting and able to prevent an over-hasty and erroneous reaction.

The Standardization Working Draft for PWI 14.8 (see PWI 14.8 — *Standardization Working Draft for PWI 14.8 — Lane Departure Warning Systems* — ISO TC 204/WG 14, NP 123.21, Nov. 21, 2000) specifies the definition of the system, classification, functions, HMI and test methods for lane-departure warning systems (see Figure 30). These are in-vehicle type systems that can warn the driver of a lane departure. The subject system, which may utilize electromagnetic, GPS, vision or other sensor technologies, shall function in the road environment, which has the visible lane marking. The standard shall apply to vehicles, trucks and busses.

The standardization draft defines lane attributes (markings, width, etc.), time-to-line-crossing, trigger lines (earliest, latest, etc.) and warning aspects (condition, etc.).



Key

1 lane boundary
2 warning threshold
3 warning condition
4 lane departure
5 latest trigger line
6 lane-departure warning
7 suppression request

Figure 30 — Lane-departure warning system (PWI 14.8)

The human interface requirements will be defined in collaboration with TC 22/SC 13/WG 8. The following issues are proposed.

— **Warning presentation:** An easily perceivable tactile and/or audible warning shall be provided.

— **Interference with other warning:** Even when a vehicle is equipped with LDWS along with other warning systems such as FVCWS (Forward Vehicle Collision Warning System), the warning shall be clearly distinguishable to the driver.

— **Indication of the system status:** If a symbol is used to notify the driver, a standard symbol shall be employed. The system status indication shall be easy for the driver to understand.

— **Activation:** The lane-departure warning system may be fitted with a system "on/off" control that can be operated by the driver at all times.

— When only tactile and/or audible warnings are used, the warnings may be designed to indicate the direction of the departure (position of sound source, direction of movement, etc.). If the tactile and/or audible warnings are not designed to indicate the direction, a visual cue may be used to supplement the warning.

— The system may suppress additional warnings to avoid multiple nuisance warnings.

In a simulation test, where 11 men and 11 women had to drive for 3 h per person [30)], 90 % of drivers have started to react within 0,9 s, even in a low level of awake condition (PWI 14.8). Out of the 22 drivers, no one exceeded 1 s. Hence, it proves that 1 s is required by the system for warning.

Well-founded experience with warning concepts in Lane-Departure Warning Systems is already available. A Japanese system combines all three essential modalities, including steering torque, which reduces the response time. The time to departure has to be carefully designed not to annoy the driver with too many warnings. The Standardization Working Draft for PWI 14.8 specifies the definition of the system, classification, functions, HMI and test methods for Lane-Departure Warning Systems. The human interface requirements will be defined in collaboration with TC 22/SC 13/WG 8, concerning warning presentation, interference effects and specific design features.

10.5 Manoeuvring aids for low speed operation

Manoeuvring Aids for Low Speed Operation (MALSO) are detection devices which are intended to assist the driver during low-speed manoeuvring (see Figure 31). MALSO Systems indicate to the driver the presence of front, rear or corner objects when squeezing into small parking spaces or manoeuvring through narrow passages. They are regarded as an aid to drivers for use at speeds of up to 0,5 m/s, and they do not relieve drivers of their responsibility when driving the vehicle.

For the driver interface, two or more progressively critical levels of warnings are fed back to the driver regarding the hazard environment. At a minimum, the audible information channel shall be used. Visual information and warning may be used as a supplement. A standardized information strategy will be the basis for the development of the information components for both types. The most relevant information for the driver is the distance, i.e. clearance between the vehicle boundary and an obstacle. As additional information, the relative location of the obstacle to the vehicle may be indicated.

The following guidelines for the implementation of an information strategy are given.

— Distance shall be coded into at least two levels. These zones may be represented by different repetition rates with the basic rule that a high repetition rate or a continuous sound corresponds to short distances.

30) Without further specification of the method.

— The different areas may be represented by different carrier frequencies (e.g. high frequency for front, low frequency for back of the vehicle). In this case, not more than two different areas/carrier frequencies should be used. Synthesized or recorded voice messages may also be used.

— The activation/deactivation of the system and the indication of failure/disturbance may be presented by an audible signal clearly distinguishable from the other signals.

If the visual information channel is used as a supplement to the audible channel, the following basic code is recommended.

— The information shall be coded into at least two levels, represented by different colours, red for level 1 (imminent collision level) and yellow or green for level 2 (attention level). The two levels may be subdivided by using more than one display element with the same colour, e.g. a bar-graph with three red and three yellow bars, allowing for six sub-levels.

— The display should be located so as to minimize the likelihood of inducing drivers to change their glance direction. For example, it is recommended to place the display for the rear monitoring range in the rear part of the passenger compartment, because this allows drivers to watch the display at the same time while looking through the rear mirror or over their shoulder directly through the rear window.

— It is recommended to indicate the activation/deactivation of the system by a telltale or a symbol in all active displays of the system.

Dimensions in centimetres

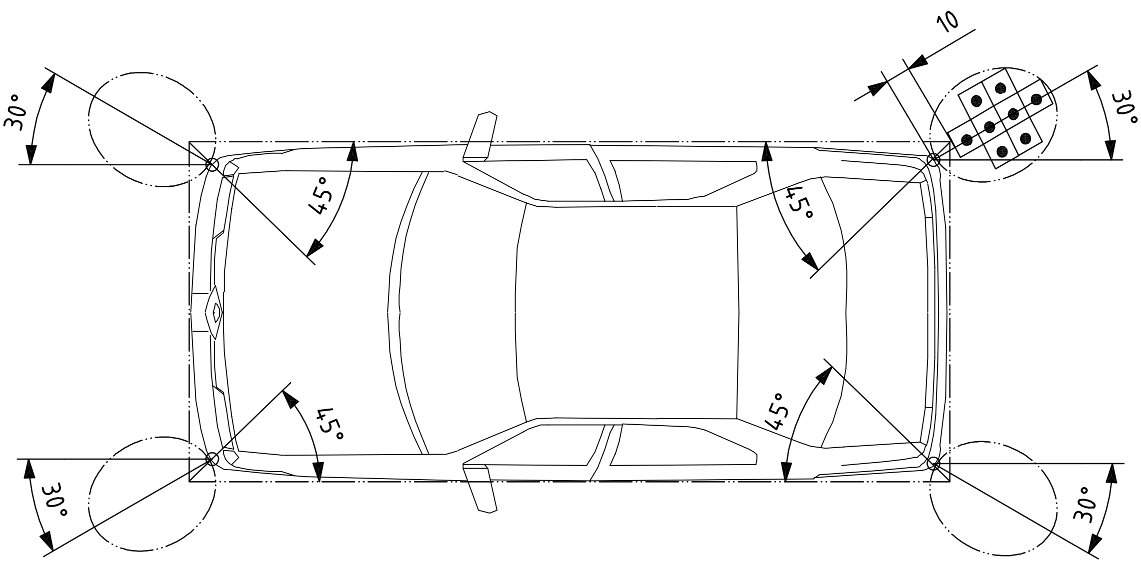


Figure 31 — Manoeuvring aids for low speed operation (MALSO) (Anonym, 2002)

The man-machine interface of the Manoeuvring Aids for Low Speed Operation (MALSO) prioritizes the auditory warning with a possible visual additive. Distance, location and activation state have to be coded by different attributes of the auditory signal. A combined auditory/visual warning is not excluded.

10.6 Usability of intelligent-transport-systems information for drivers

Uno *et al.* (2001) described in a study a tentative procedure for managing the ITS information presented to drivers so as to minimize interference during driving and promote safety. The information for drivers can be distinguished between warnings, route-related information, and multimedia services. The presentation of warnings should take precedence; route-related information requiring the driver's immediate attention should give secondary priority. Route information and multimedia services not requiring immediate attention can be presented if warnings or essential route information are not presented.

Very important for managing warning-related information is giving the driver enough time to react or to complete actions. Route-related information should be presented in a timely manner if driver reaction is demanded in a short time. In contrast, timing is not so important for route information that does not imminently require driver reaction. Multimedia information should mainly increase driver convenience.

Uno *et al.* carried out experiments to clarify the requirements for visual presentation of ITS information in order not to distract the driver's attention. They compared the effects of graphic and text displays on driver reaction times. Two information items of the same urgency were presented simultaneously. Results showed that drivers needed more time to respond to text information than graphic information. Moreover, time for text information increased as the number of characters increased. Graphic displays do seem to have advantage for presenting ITS information needing immediate driver reaction.

Based on the above results, Uno *et al.* devised a tentative procedure to manage in-vehicle information for drivers. The management system determines the category and priority of the information item and sets the time margin until the driver needs to react. To be able to convert into real driving situations the management system decides if an item is a warning. If the item is a warning, the management deletes all other information items presented to the driver and writes a warning item. If the other items are warnings, too, the management systems ranks the items according to priorities and timing requirements. If the information item is not a warning, the management system determines whether the item is route-related information. If it is, the management system has to decide the reading and the reaction time. The management system deletes and overwrites non-imminent route information and multimedia service if the time margin is small. The management system treats route-related information with a large time margin in the same manner as multimedia information. The information remains for at least the minimum duration the driver needs to understand it.

10.7 Other assistance systems

Adaptive Cruise Control Systems: Adaptive Cruise Control Systems (ACC) keep a desired speed and distance to the preceding vehicle. The speed is controlled, if necessary, by automatic braking. ACC functions are extended from motorway to urban and congestion environments (stop-and-go traffic). Key elements of ACC systems are the display and interaction concepts (Fastenmeier, 1998). Critical moments and changes of functions have to be signalled to the driver, e.g. the activated state of the system has to give clear feedback.

In a study by Nirschl and Kopf (1997), with following and approaching tasks, the secondary task was to detect a lamp in the middle of the dashboard, which flashed for up to a maximum of 10 s (if the subject did not recognize it and switch it off manually) [31]. The average detection rate of 63 % to 89 % depended on the ACC adjustment (medium, hard, soft). Instead of using a visual signal, speech output can be used to specify the approach to a preceding vehicle (see 6.4.5).

Curve forecast: The future generation of navigation systems can be used to calculate the course in front of the vehicle (Hamberger *et al.*, 1997). The driver can be warned if it seems he is going to overlook a crossing or if he falsely assessed a curve and his speed is not appropriate for the curve characteristics. The authors stress that too low a threshold for warning should not be set. Frequent unnecessary warnings annoy the driver and are then no longer observed.

31) Although the detection task was methodically chosen as a secondary task, it can be conceived in the present context as a warning lamp.

There are several other assistance systems, which are not discussed here. No extensive experience with the appropriate warning methods is at hand as yet.

11 Warnings in other applications

11.1 Aircraft

There is a plenitude of data about warning systems in military and civilian aircraft, which can be advantageously exploited for vehicle applications. Some of the most interesting aspects are presented in the following (and in the respective clauses).

In the aviation environment, an attention or master alerting signal is used, supplemented by secondary displays, the latter indicating the exact nature of the alarm (Tan and Lerner, 1995). Since the number of warning displays on a flight-deck is high, these displays are often grouped based on the system being monitored. The master alerting signal draws attention to these grouped displays and further information may be conveyed by visual means. An example of such an arrangement would be an engine fire alerting system on the flight-deck. For such a system, a unique alarm for "engine fire" is sounded and visual indicators, located together on a panel, indicate where the engine fire has been detected.

There are efforts to realize an efficient MMI for Ground-Proximity Warning Systems (GPWS, Wischmann *et al.*, 1999). Possible MMI solutions are (visual) 2D- or 3D-representations of the flying situation or powerful speech output. The visual representation could include the path, the terrain and the collision detection. A 3D-perspective display would need a careful design to avoid any wrong impression. So, for first tests of a GPWS a simple 2D-display was realized, which was claimed to give the pilot a fast and safe overview of the situation. It consists of two concentric circles divided into eight differently coloured segments. The circles represent the distance to the hazard, the segments stand for its direction, and the colours yellow and red represent the different urgency. The different segments can be differently coloured simultaneously.

An extended overview of auditory signals in military aircraft is given by Doll and Folds (1985). Their literature review is incorporated in the equivalent Clause 6. In the following some essential results are listed.

Even in the years before 1985, a relatively large number of auditory signals were used in military aircraft. The basic advantage of auditory signals is to alert the aircrew to (potentially) dangerous situations. The mean reaction times for the no-tone are much longer than for tones (Bate, 1969). The general statement of Patterson (1982) concerning the current applications of auditory warnings, however, was rather negative:

> *"When a warning occurs it is usually either a false alarm warning or the direct result of a standard flight procedure. Even when a true warning occurs, it almost always indicates a potential problem rather than a sudden emergency."*

The warning meanings are difficult for the aircrew to recall (Doll and Folds, 1985). Some non-speech signals are sufficiently similar that they may be confused, particularly in high workload situations. The criticality of the warnings is not reliably indicated by any characteristic of the signals. The basic problem areas are: reduction of loudness, enhancement of the distinctiveness and masking resistance, concurrent warning signals and additional uses of auditory information.

Studies of currently-operational alerting systems have identified non-conformance situations where pilots have delayed in responding to automatic alerts, or have executed different resolutions to the hazard than commanded by the automatic system. For example, pilot questionnaires on the use of Traffic Collision-Avoidance Systems (TCAS) reported that pilots intentionally did not follow commanded manoeuvres in 24 % of the cases where alerts and commands were given, suggesting that the TCAS manoeuvre is not always what the pilots would do instinctively (Pritchett, 1997).

The author investigated the pilot's non-conformance to alerting system commands. Pilot non-conformance changes the final behaviour of the system, and therefore may reduce actual performance from that anticipated. Two simulator studies have examined pilot non-conformance, using the task of collision avoidance during closely-spaced parallel approaches as a case study. The studies discovered subjects decisions to alert, and their selected avoidance manoeuvre, differed from those typically commanded by the collision-avoidance systems.

The pilots' perceived need to confirm the alerting system's commands may involve several factors, including the following.

— The pilots may be concerned that the alerting system will fail to act as it should.

— The pilots may feel the alerting system cannot consider relevant information or has different objectives.

— The pilots may place greater confidence in their own decisions than in the decisions of the alerting systems.

The existence of auditory warnings in avionics systems over many years is a hint to consider more auditory warning systems in vehicles. Of course, the situation while flying and while driving is somewhat different; however, the basic demand of time-sharing tasks and "online" reacting is comparable. Also the noise conditions in vehicles are considerably more suited to auditory signals. However, there are sceptical statements as to the overload with auditory warnings in aircraft, which should also be considered for vehicles.

11.2 Intensive care unit

In an Intensive care unit (ICU), non-verbal audible signals are employed to convey information of a critical nature from instrument to medical personnel (McIntyre and Nelson, 1989; Edworthy and Meredith, 1994). These play an established role in promoting patient safety. Intensive care units differ from operating rooms in that the patients are more often conscious and visitors are occasionally present. Environmental concerns about the delivery of warning messages in intensive care units exist in the belief that conventional non-verbal alarm signals are perceived to be threatening by some patients. There is also a significant opportunity for error in interpretation by fatigued or anxious personnel.

An ICU audible system should

— warn that immediate attention to a patient is necessary,

— indicate the location of action required,

— provide some information about the action likely to be required,

— encourage compliance with the information received, and

— possess an intrinsic character that does not encourage inappropriate use of the warning device.

A laboratory investigation of automatically-delivered human-voice signals for an intensive care unit with two mechanical signal tapes (tonal signals) and two speech outputs was conducted (McIntyre and Nelson, 1989). The verbal signals were overwhelmingly superior as compared to the mechanical (see 6.4.1).

The demands of personnel in intensive care units do not have much in common with those of drivers in vehicles. Nevertheless, the use of speech output in this area demonstrates that spoken warnings can be used to specify quickly and efficiently and to draw attention to life-threatening situations.

11.3 Industrial plants

In industrial plants, it is the task of the operators to observe the patterns of the alarms and status indicators, to interpret the situation, and to deduce the corrective actions that are needed (Roscoe, 1985). Krigman (1985) did a survey of InTech readers among monitoring and control professionals about the role of the operator. The results are summarized below.

Some of the blame for alarm-system shortcomings has to do with operators who are improperly trained or supervised (Krigman, 1985). Alarms are often acknowledged then ignored just to silence the alarm horn. It is not unusual to find that the alarm horn has been disconnected.

Alarm-system shortcomings are also attributed to poor engineering (Krigman, 1985). Badly-conceived systems can lead to operator tendency to ignore any alarm that arises. Nuisance alarms are a prime problem (see 2.2, False signals). They occur when the alarm does not really represent a problem or when there are difficulties in the warning system rather than in the monitored processes.

Other engineering inadequacies are

— alarms with insufficient information,

— inconsistencies,

— alarm systems that overwhelm the operator with warnings.

Today's process operators are presented with an ever-increasing number and complexity of alarms and information displays. The problem of a high alarm density has been further exacerbated as new acquisition and display technologies are integrated into the control-room environment. The amount of information, both relevant and irrelevant, that the annunciators present may easily overwhelm the control-room operators. While research had begun prior to the Three Mile Island accident, that event acted as a catalyst for a generation of work in the area of information display and human factors.

This problem can be markedly reduced by bringing the operators' attention to only the most important, pertinent, and qualified data. The proposed methods are: suppression of irrelevant alarms, delay of secondary alarms, grouping of alarms, combining of redundant alarms, and separation of failed functions. The system should not annunciate normal operation. Multiple alarms about a single process condition should be suppressed and only one alarm should be activated. As many as 38 % of alarms may be suppressed with impunity.

The purpose of a prioritization system is to extract only the most important data, which is achieved by using logical combinations of signals to form alarms (Roscoe, 1985). There are two types of priority: dynamic (changes with variable plant condition) and static priority (constant as plant conditions vary).

Static prioritization allows users to assign a priority level to an alarm. Any time that alarm is activated, it is displayed at the assigned priority. In some cases, that assigned priority may not be appropriate for the circumstances. There are different methods of assigning alarm priorities: Chronological alarms are in wide use, showing the order in which related events occurred (Krigman, 1985). Alternately, the prioritization can be based on the degree of urgency, which clarifies when immediate attention is needed ("hazard-based priority"). Some systems may allow the operator to choose a priority scheme whenever he presses a priority button. The dynamic prioritization system, e.g. the Alarm Filtering System (AFS, Corsberg, 1988), is another step towards more effective processing of alarms. It determines the importance of alarm information relative to the current plant state. When an alarm is activated, AFS assigns a level of importance to it based on the set of all currently activated alarms in the plant. As other related alarms are activated or deactivated, that level of importance is re-evaluated and possibly changed. Thus, the prioritization is dynamic, changing as the plant state changes. AFS uses relationships between alarms as a basis for determining priority levels. These relationships resulted from applying expert system concepts to the problem.

There is a trade-off between warning signals and automated trips (Krigman, 1985). The following is a combined approach. If the condition is sufficiently grave, automated controls trigger an appropriate action. Other less grave conditions are presented to the operator for a decision on the appropriate action. The ability of operators to override trips is also a matter of debate.

Standardized acknowledgement procedures are often given in industrial plants (Krigman, 1985). Critical alarms should at least require acknowledgement and should remain displayed until the associated condition is removed. Most of the professionals in industrial plants desire some form of checking if the troubleshooting actions were also actually carried out by the operators. Dummy alarms can be initiated and the responses by the operators observed.

Alarm systems are generally considered to be ineffective if they simply indicate a possible problem but afford operators little means of verifying the condition (Krigman, 1985). Operator personnel often start assuming that an instrument rather than a process condition is the cause of an alarm. Therefore, redundancy is a corporate standard on critical alarms.

On the basis of the experiences in industrial plants, one can forecast some of the problems of using alarms in vehicles, even though the time conditions are quite different. These problems may include a bad consideration of an alarm by the user because of nuisance alarms, high density of alarms and other engineering inadequacies. The different alarm philosophies in industrial plants can give some clues for the design of alarm systems in vehicles, especially with respect to prioritization. Suppression of irrelevant alarms, delay of secondary alarms, grouping of alarms should be considered. It is even conceivable that some kind of acknowledgement of the alarms is introduced. Verification in the car environment means giving the driver as much detailed information about the underlying problem as necessary to build up a mental model about the problem.

12 Discussion

There is a great deal of experience and experimental data about the presentation of visual and auditory warning signals in aircraft cockpits and vehicles. This holds true for the psychological and physiological factors which result in the recommended warning-system design parameters. The sensorial, coding and organizational parameters of warning systems are relatively well-known, which partly stems from experiences gained from more classical information systems like vehicle malfunctions, navigation systems, etc.

Nowadays a visual warning signal like a symbol, icon or text can be readily specified so that a maximum of detection and classification probability is obtained as well as a minimum of distraction and confusion with other information. This can be regarded as basic human factors knowledge. The optimal sign size, colour, kind and number of words, etc. for warnings in a moving vehicle, taking into account the specific conditions occurring during driving, are known.

Nevertheless, this knowledge is often not observed even in modern cars, e.g. with respect to colour and position. Other design ideas have still not been implemented, e.g. apparent motion, prioritization and master caution.

There is less experience with tonal signals and even less with auditory icons in serial cars. There are bells and buzzers as warnings for bad states in the moving car (not applied seat belt, etc.) and in the standing car (headlights still on, etc.). But there are relatively few auditory warning signals for dynamic driving situations, though the specific advantages of tonal signals are well known. The recommendations for the sensorial, coding and organizational parameters are derived from machinery safety, avionics and theoretical calculations. So, tone type, signal frequency and level, and temporal characteristics can be specified with sufficient certainty for different priorities of tonal signals.

The startling effect can be met with a soft onset. The application of tonal signals is very much restricted by the requirement of clearly discernible and quickly recognizable tonal signals and auditory icons. The acoustical medium never allows the simultaneous presentation of more than one tonal signal, which makes prioritization necessary.

The idea of spatial coding techniques and auditory icons in cars, which can be very useful and important for modern warning systems in emergency situations, is relatively new.

Speech output as a unique form of auditory signals has the considerable advantages of alerting and simultaneously conveying a clear message. Automobile companies, however, hesitate to implement speech output in cars because of its obtrusive characteristics. The usefulness of spoken messages has been largely proven within the avionics, and some parameter recommendations can be transferred into cars, e.g. voice, vocabulary rules, preceding tones, etc. The specific characteristics of the acoustic media, such as startling effect, serial information conveyance, prioritization, etc. have to be considered.

A main problem of speech output in time-critical warning systems is to keep message length and the commanding quality of a human voice on an adequate level. The design of the spoken messages has to be orientated at the urgency of the warning. Speech output has clear advantages as compared to tonal signals with respect to flexibility and learning level.

Very little is yet known about tactile warnings. There is an excellent perceiving-acting compatibility and a natural association between the tactile display and the situation it represents. Tactile warnings can be given through the steering wheel or through the accelerator pedal. This is acceptable to the user and possibly better than warning by sounds. However, there are few unverified recommendations as to the parameters of tactile displays (frequency, intensity, duration and pulse rate).

Consideration has to be given to variations of redundant message presentation. The Stroop effect (decreasing reaction time with redundant information) can be used advantageously in time-critical warning systems. The visual/auditory combination is widely used by designers and therefore does not appear to be very new. However, care has to be taken when modifying, for example, colour, blinking, text, other visual messages, etc. Industrial warning systems can be the baseline for those combinations. Icons mixed with speech output are an interesting and promising combination.

Whether a master alerting signal is useful in cars remains to be discussed. It cannot be assumed that the concentration of different warnings in an aircraft, with many aggregates and a 3D environment, onto a single master alerting signal will be generally necessary in cars. However, dangerous driving situations can easily imply several warnings, e.g. the driver is neglecting his steering task and approaches a neighbouring lane. In this case, several warnings with respect to lane departure, side collision and curve forecast would lead to a jumble of auditory, visual and possibly tactile signals with the danger of startling and confusing the driver. In these situations, a master alert can be profitably applied.

Other advanced concepts, such as graded sequences of warnings and parallel changes in modality, should be considered because of their promising potential.

Various experiments with warning signals can be categorized into the scheme of type, code and modality of information. This is useful to obtain an overview and to specify the conditions of the experiments in detail. Results with verbally- and non-verbally-coded objects as well as with spatial and abstract information are available which lead to appropriate recommendations.

Several new assistance systems are being developed and implemented in series cars. In particular, those affect the primary driving tasks (LDW, SOW, ACC, etc.) by indicating time critical functions or situations which have to be carefully signalled to the driver. This challenge requires the designer to implement all that is known about the presentation of warning signals, e.g. display parameters, sensorial modality, coding and organizational techniques, prioritization etc. This is even more important since a warning not only includes the attention-getting signal but may also include status information and provide instruction for a needed action.

The most advanced of the primary driving tasks assistance systems is the distance warning system, where sophisticated visual and auditory warnings are available. Collision, obstacle and lane-departure warning systems need to exploit the Stroop effect to get fast responses from the driver. Here, different time-related parameters, auditory 3D displays, auditory icons and perspective visual displays which deliver a good base for further R&D are proposed.

The immense experience with warning systems in other domains, particularly in avionics, can be profitably used for warning systems in cars. In addition to the master alerting signal mentioned above, 2D representations are good examples for their potential use in cars. The problems of warnings such as a multitude of different signals, low confidence, non-conformance, etc. were investigated in aircraft.

In power plants, with many aggregates and a plenitude of possible alarms the issues of assisting a mental model, acknowledgement of the alarms, filtering, prioritization and automated overriding are of relevance. Even if the time conditions cannot be transferred to automobile traffic there are different approaches to coping with many simultaneous alarms.

13 Summary

13.1 Introduction

The working group ISO/TC 204/WG 14 is carrying out a survey of warning systems with a main focus on vehicle application. The survey should be the basis for standardizing activities. It includes the current studies of ISO/TC 22/SC 13/WG 8 and ISO/TC 204/WG 14 as well as other relevant publications.

The driver has to deal with a lot of information which has different situation-dependent priorities and which is more or less expected by the driver. For the future, a great deal of information about the vehicle and the environment can be measured and communicated to the driver.

The designer is trying to influence the behaviour of the recipient of the warning in some way. A difference has to be made between behaviour which occurs naturally in the relevant situation, without a warning necessarily being present, and the ‘added value’ that the warning might bring.

13.2 Warning signals

The word “warning” implies a range of levels from simple situation indications to more imperative warnings, and of commands directed toward the driver to perform a certain task. The first component of a warning device consists of a mechanical device that uses sensor logic to determine if and when to trigger a signal. The trade-off between minimized false signals and maximized sensitivity has to be optimized.

The second component of an emergency signal response paradigm is the human operator, who is responsible for detecting, evaluating, and responding to the signal that is generated by the sensor-based signalling system.

Warnings are representations of the situations to which they refer. Most warnings serve two functions. These are the alerting function, which is somewhat abstract and emotive, and the informing function, which is more explicit.

False, missing and conflicting signals may undermine confidence in system accuracy and reduce subsequent reliance and adherence. Different situation perception by the driver can also result in disregarding the warning signal. Well-chosen warning criteria are possibly more important than the ultimate choice of specific details of the warning signal.

ANSI standards have made the following signal words standard for communicating hazard intensities:

— **DANGER**: immediate hazard which will result in severe injury or death;

— **WARNING**: hazard or unsafe practice which could result in severe injury or property damage;

— **CAUTION**: hazard or unsafe practice which could result in minor injury or property damage.

This can be used as a general classification of signals in the car which try to attract the drivers attention to any hazardous state inside or outside the car. The communication function of a danger, a warning or a caution signal is to alert users to the presence of a latent hazard, let them know how hazardous it is, and tell them what to do to avoid the hazard and what will happen if they do not act appropriately. The statement of the hazard can be in speech, text format or in pictorial/symbolic form.

Urgency as one particular iconic feature of warnings should relate in some systematic way to the hazard or risk of the referent. Warnings can be said to be appropriately mapped when the rank ordering of the urgencies of the warnings with which referents are associated is positively correlated with the rank order of the urgencies or importance of those referents.

Alarm theories are useful to understand the reaction to warnings, e.g. Classical Signal Detection Theory, subjective Expected Utility Model, Fuzzy Probabilities and Multiple Resource Theory. These theories all make significant contributions to the understanding of operator behaviour stimulated by emergency signal failure. The designer of warning systems should consider the presumed balance of risks by the user, his habituation and the multiple resource theory which involves different sense modalities and signal codes.

Low signalling-system reliability may have detrimental effects on signal response speed, accuracy, frequency and response decision appropriateness. Operators may have a tendency to match their response rates to signal reliability. Operator mistrust has interactive effects with task workload and alarm system reliability.

13.3 Psychological and physiological aspects, sensorial modality

Because of the severely limited capacity of the human to deal with incoming information, at some stages of the analysis only a small portion of the incoming information is selected for further processing ("attention"), which is important for the concurrence of the primary task and warning. There are different stages of human processing of warnings, i.e. directing attention, decoding of warning and situational orientation. The reaction time to warnings depends on number of options. The fewer the options, the lower the reaction time is.

New assistance systems can relieve the driver or create an extra workload. In the case of extra workload, the driver has the potential of compensation or additional mental effort to counter this burden. Warning systems may fall into the category of “relieving”, i.e. the overall workload is decreased and hazards are efficiently encountered (which is the objective of warning systems).

Expectancy refers to a predisposition to believe that something will happen or be configured in a certain way. In complex situations, it helps to free the driver from some basic concerns so that attention can be focused on more important matters. For example, good symbols make intuitive sense to the driver, and are easily learned and recognized. It can be argued that even the best-designed warning will not override the beliefs and expectations that the individual brings to the situation.

The developers of warning systems must consider other human abilities and variability, i.e. attention, perception, comprehension, memory, fatigue, age, education.

For automobile applications, displays with different sensorial modality have to be differentiated: optical (sight, visual), acoustic (hearing, auditory) and haptic (touch, tactile) displays. Acoustic and touch displays result in the shortest reaction times. According to the multiple-resource theory, cross-modal task and information presentation should lead to more efficient processing and improved task-sharing performance.

The choice between visual and auditory information presentation depends on the physical properties as well as on physiological/psychological attributes of both sensorial channels. Visual displays are, for example, suited for many, long, complex messages which are not very urgent. Auditory displays are, for example, suited for few, short, important information for sequential information transfer. Tactile information is faster and more accurately detected and processed than visual and auditory information, especially when additional tasks are performed.

13.4 Visual warning signals

Visual displays can be categorized according to their content (actual value display, etc.) as well as in respect of their codes (analogue displays, etc.). Any visual warning displays have to consider the visual sampling process of the driver. A certain range of number of glances and total glance time should not be exceeded, even though the experienced driver is capable of distributing his glances among the forward and in-vehicle view. The design of visual warnings has to ensure a relatively fast reading even for older drivers.

A driver has to receive and process information and react to it, and this may be divided more elaborately into: searching, classifying, memorizing, supervising, comparing, calculating, etc. These processing phases depend differently on the characteristics of information, like sign size, colour, arrangement, etc.

Sensorial-related parameters of visual displays concern those characteristics of a visual display which affect the "mere" perception of a visual signal by the eye. There are many sensorial-related parameters for visual information, such as size, brightness, contrast, etc. which contribute to visibility, readability and legibility.

Extensive data on how to design visible and legible alphanumeric information to increase acquisition performance and minimize fatigue is currently available. Research has shown that signals should have unique position, unique size and unique shape.

Important visual information such as warning signals should be positioned near the forward line of sight. If no further accompanying auditory signal is given, it should be located at the upper parts or upon the dashboard or even in a head-up display. The display should be designed to keep accommodation and adaptation to a minimum, e.g. with a virtual display. Coloured steady warning signals must be located at the upper parts of the instrument panel. Blinking signals could be positioned anywhere in the dashboard.

The height of warning signs should consider adverse conditions; hence it should amount to about 10 mm. Alphanumerical warning information should have a size in the order of 20 mm. Size in itself adds to detectability but compromises the compactness of a display. A compromise has to be found between a sign size and compactness. A crowding of display information has to be prevented.

Visual information can be coded by size, shape, colour, blinking, etc. or by combinations such as size/colour, etc. In redundant coding, differentiating characteristics of codes depend on each other. If absolute judgements have to be made, a maximum number of code levels should not be exceeded, depending on the code.

Symbols are graphical signs which transmit messages independent on speech. They can represent objects, states, functions, events and instructions. The result is like an alphabet where each sign represents a significant item. Symbols can be classified according to their proximity to realism. Symbols with a low abstraction level are called representational displays or pictograms (icons), those with a high abstraction level “symbols”, both are subsumed here with “symbols”.

The advantages of symbols are language independency and faster recognition but the user has to know the meaning of the symbols. ISO 2575 is the International Standard for symbols in vehicles. Drivers understanding of several symbols has remained at the limit of acceptability. Their meaning can completely missed through a lack of knowledge. The rarer the symbols presented, the higher the risk of a lack of understanding. Thus, the presentation of just symbols for warnings in vehicles is critical. If symbols are used for warnings, they should be accompanied by textual or spoken speech for action instructions.

Textual warnings in vehicles should be used and designed specifically for vehicles. There are clear rules how to design textual warnings. They should be preceded by a tonal signal, be concrete, simple and should not include more than a few words. Textual warnings have to communicate the information in ways that users will understand, believe and use. The text must clearly indicate the hazard level and statement as well as the consequences. Critical and procedural information should be distinguished. Abbreviations should not be used.

The colour code has some specific advantages when several pieces of information are displayed and have to be distinguished, i.e. clarity, conspicuousness, less fatigue. Colour is superior to most other codes, redundant coding included. The more information elements, the more marked this advantage is. Thus, colour should be used if objects have to be found between many others, classified among restricted class number, and arranged clearly and pleasantly.

There is a stereotype interpretation of specific colours in vehicles, e.g. “Red” for “Danger”, “Blue” for “High beam”, etc. Colour deficiencies should be encountered by redundant coding, i.e. the coloured signs including other codes beside colour. The characteristics of the human vision for colour contrasts have to be considered.

The blinking code is very conspicuous. Blinking draws the attention of the observer because the eye periphery is very sensitive to brightness changes. Static objects which can not perceived beyond 20° from the main line of sight can be detected if blinking. A blinking frequency between 2 Hz and 10 Hz is recommended. The main disadvantage of the blinking code is the danger of annoyance. Not more than 2 synchronously-triggered elements should blink at the same time.

Movement is a well-established strategy for enhanced signalling in the periphery. The simplest implementation of a moving luminous warning signal is to put a target into stroboscopic apparent motion. A vehicle icon for too fast for curve ahead is a curved arrow placed in apparent motion.

The perceptual weaknesses of the human in a front-to-rear-end collision situation could be reduced by a warning system with a display which indicates headway/following distance and the change in velocity of the forward vehicle. In addition, it could take driver brake reaction time, linear perspective and relative size information into account.

Concerning the organizational parameters of information displays the spatial, temporal and content related structures of a technical system have to be mapped onto the display according to basic psychological rules, i.e. grouping, consistency, etc. An approach to distinguish between alerting and informational aspects of a warning could be the fisheye principle. Other organizational aspects of a display arrangement have to be regarded such as density and layout complexity.

Multiple visual warning messages have to be prioritized according to a priority classification, especially if they are to be presented together with other visual displays in the same space in the panel. There is a sufficient number of possible codes being appropriate for prioritization, primarily position and colour. A master caution is known from avionics and could also be used advantageously in automotive systems. It permits the reduction of the number of isolated displays and controls and guarantees fast detection because of its central position.

13.5 Auditory warnings

The multitude of information to be displayed to the driver through information systems may create the need to minimize visual load and make more and better use of auditory channel. The proposal for the standard "Auditory information presentation", ISO TC 22/SC 13/WG 8, will provide ergonomic specifications for the design and installation of auditory displays presenting speech and tonal information while driving.

The following auditory warnings are distinguished:

a) tonal signal, e.g. an intermittent tone;

b) auditory icons, e.g. sound of a tyre skidding;

c) speech output, e.g. spoken instruction "Brake !".

When envisaging the use of auditory signals or speech as warning signals, the specific human processing mechanisms have to be considered. There are different steps coupled to the echoic memory which transform the original signal into a meaningful code, whereby matching with expectancy is a central factor. On the one hand, with auditory presentation there is good chance of making use of the human capability of dividing attention, especially in the driving environment. On the other hand, there are specific pitfalls (annoyance, etc.) which must not be ignored.

Auditory presentation is recommended when vision is limited or impossible, because it is omnidirectional, since it is a supplement to overloaded vision and it can draw attention to visual indicators. Too many auditory messages or unimportant messages will result in user habituation and then the users will simply not respond to the signal at all.

Certain attributes for tonal warning signals are judged to be important, especially conspicuousness, discriminability, meaning, urgency and response compatibility. Disturbing effects like the startling effect and annoyance should not be underestimated (see below).

For in-vehicle signals audibility should be as high as possible (usually 95 %). For this reason, tonal warning signals should have frequencies between about 500 Hz to 3 000 Hz. To take older population into consideration, the discriminating frequencies should be below 2000 Hz. The signal frequencies should be as different as possible from the most intense frequencies of the noise in vehicles, and a broadband sound or a mix of narrow-band sounds is recommended.

The selection of an optimal sound amplitude is a matter of balancing listener comfort against message audibility. Three different "usable auditory areas" are defined: Limit area, comfort area, emergency area, differing in sound amplitude and signal-to-noise ratio. For warning signals which have to be reacted to immediately, the emergency area with L_{eq} = 70 dB (A-weighted) to 90 dB (A-weighted) and SNR = 10 dB (A-weighted) to 15 dB (A-weighted) is recommended. Because of the large variation in background noise, it would be desirable that the signal level adapts automatically to the frequency spectrum of the background noise.

A balance has to be found between alerting and annoyance by auditory signals. The more conspicuous an auditory signal, the more it attracts the listeners attention, but the risk of it being disturbing is greater. A compromise is a soft onset of the signal, with moderate loudness. The stimulus should be between mild and intense, while avoiding a startling effect. A way should be found of keeping up the correct expectation of warning signals, e.g. by including them in the check of a starting vehicle.

Tonal signals: Tonal signals must be learned by drivers (association between signal and message). Especially in the case of rarely-displayed tonal signals, regular exposure may be necessary to clarify and reinforce their meaning. If a corresponding visual information exists, both should be displayed at the same time. In addition, the number of tonal signals used in a vehicle should be limited with respect to intelligibility and discriminability.

There are a number of tonal alarm sounds like horn, bell, buzzer, etc., all with specific characteristics with respect to attention-getting and noise-penetration ability. They include different urgency cues from announcing to caution and danger. Warning tones should have at least some sort of time-varying or intermittent character.

Because simultaneous messages can be difficult to understand, auditory inputs have to be presented serially. This means that all in-vehicle auditory displays must be connected together in such a way that messages are co-ordinated on the basis of priority. Thus, prioritization with respect to urgency is a major concern while designing warning sounds. Many dimensions of an alarm (speed, repetition rate, pitch, etc.) can affect the perceived urgency of the alarm. The time characteristics seem to be the most efficient ones.

Tonal signals have to be discriminated clearly. One aspect is the number of tones, which should be restricted to about four when absolute discrimination is required and the strict prescription for military aircraft is adopted. If multiple dimensions (sound level, temporal distribution, etc.) are used and the signal is combined with text or speech, then considerably more sounds can be used.

The temporal attributes are one of the most important characteristics of tonal signals. They serve as attention getting and as a discriminability factor as well as urgency cues. Intermittent beeps repeated at rates of 1 to 8 beeps per second or warbling sounds are recommended for warning alarms in vehicles. Pulse format and time between pulses influence the perceived urgency significantly. Urgent warnings should have a higher signal repetition rate, a higher intensity and a higher fundamental frequency than cautionary warnings.

With oncoming collision warning systems in vehicles, spatially-coded auditory signals are getting important. The human is capable of differentiating different directions of sounds if the signal is designed adequately and speakers are located carefully. The detection and localization of vehicles to the side of the subject vehicle, can be assisted by broadband auditory 3D displays, analogous to the spatial location of a dangerous threat in military aircraft. Auditory signals can facilitate reading of visual displays if they are close together.

Auditory icons: Auditory icons have been demonstrated to be superior to conventional signals with respect to recognition and reaction performance in specific scenarios. Auditory icons as intentional warnings may be useful in depicting incidental warnings well in advance of a critical situation. Specific auditory icons are associated with specific driving situations. Urgent auditory icon sounds such a tyre-skid result, however, in more false reactions than the traditional warnings. Considerably more than six items (as in traditional tones) can be distinguished, understood and remembered.

Speech output: Speech output is efficiently used in military aircraft for different warning functions, e.g. glide slope intercept, altitude above field, etc. Similarly, it should be introduced in vehicles to make use of its specific alerting and informational advantages. Although the applications may range from situations before to after driving, its main usefulness is during driving. However, care must be taken not to overload this channel and a priority system has to be installed. The control of the speech output system by the driver has to be ensured.

Spoken warnings add an extra dimension to both written and nonverbal auditory warnings. In written warnings they add the paralinguistic elements and in the case of nonverbal warnings they add the linguistic element. There are problems of intelligibility and detectability when spoken messages are used in environments where other speech communication is used.

Speech warnings are able to convey information about the nature of a problem in addition to warning the user of its occurrence. Speech warnings are more likely to be effective in stressful conditions than coded auditory tones whose meaning has not been overlearned to the same extent. But the meaning of a voice message can typically not be understood until the message is nearly completed. Thus, a trade-off exists between reduction in the length of message presentation and reduction of processing load.

Speech warnings should be as brief and concise as possible. However, sufficient contextual information is required for accurate speech perception. Semantically-rich format should be preferred to keywords. A greater redundancy of information in spoken warnings decreases the amount of attention required in processing the message. Warning messages should be preceded by an announcement tone with a pause of 0,5 s between announcement and message. Speech displays are not recommended for very urgent and dynamic messages, however.

The voice characteristics of speech displays should be such that the messages can be easily differentiated from other speech in the vehicle (e.g. passengers talking, or speech on the radio). The voice can be natural sounding, if the voice characteristics of speech displays can be easily differentiated from other speech in the vehicle and if the voice can be heard in the noisy environment of a car. A natural digitized voice should be used when the message has untypical pronunciations, the prosodic features are essential for meaning, the message is lengthy or speed of creation essential.

Processing of synthesized speech seems to impose greater demands on cognitive processes than does natural speech and there are some problems of intelligibility. Male or female voices can be used.

Pitch contour and speech rate have some effects on the intelligibility of speech to the extent that very fast rates reduce intelligibility. The introduction of a pitch contour seems to produce a small improvement on the intelligibility of speech but does not appear to be as important a factor as some of the other factors relevant to the design of speech messages.

There are some well-established rules for the vocabulary in spoken messages, e.g. brevity, specificity, familiarity, etc. The vocabulary must be based on stereotypes and be controlled, i.e. fixed and known. The words should be polysyllables. These are essential factors for intelligibility, aptness and conciseness of a vocabulary of speech output. Speech warnings should represent the specific driving situation they are warning of, but limitations are set to the details of it. So, some form of generic warnings has to be implemented.

Voice messages should not be repeated numerous times because of their tendency to irritate the driver and upset passengers. A given speech warning should be presented no more than three times, e.g. for a given crash-avoidance warning situation, regardless of the duration of the situation.

It can be expected that the perceived urgency of a spoken warning is influenced by the prosodic attributes, as pitch, speed and intensity of the message. Urgent actions have to be signalled by short phrases (if tonal signals are excluded by any reasons). Delayed actions can be composed of several units of information, which have to be structured and designed according specific rules, such as sequential presentation, redundancy, including prosody, etc.

Both, the mechanical auditory signals (tones, auditory icons) and the spoken speech coding (speech output) have advantages and disadvantages with regard to the amount of information, necessary knowledge, time consumption, etc. The following recommendations are given: Use tones when the message is extremely simple, when immediate activity is necessary, speech signals are over-burdening the listener, and if the user is trained to the tones. Use speech output when flexibility of communication is necessary, when the message deals with a time-related, but not immediate activity, when stress situations are possible which can cause tone codes to be forgotten, and if the user is not trained to the tones.

13.6 Tactile warnings

Proprioceptive-tactile warnings transmitted via the control elements have the advantage of direct intervention into the manual control process. In addition, the timing of the warning can be controlled immediately with the driver's actions. Tactile displays are most commonly utilized in aircraft. However, tactile displays are currently not widely used in automobiles, although there are a few examples, such as applying counterforces to the accelerator and brake pedals.

Experiments clearly demonstrated the advantage of introducing multimodal feedback in the interest of supporting communication and co-ordination between human operators and highly independent automated systems. Tactile warnings given at the accelerator pedals are comparable to a visual/auditory warning combination. A pulse-like torque onto the steering wheel as a lane-departure warning can be superior to a warning sound.

There are a relatively small number and unverified recommendations for the parameters of tactile displays. These concern the frequency, intensity, duration and pulse rate. If vibratory stimuli are coded by intensity, duration, and location, the user can recognize more words per minute than with a Morse Code.

A discrete proprioceptive-tactile warning signal via the steering wheel tends to have negative effect on the quality of curve driving. A discrete proprioceptive-tactile warning should only be used together with visual information in the sense of redundancy.

13.7 Redundancy of message presentation

Different modalities can be combined to get a powerful warning system, e.g. an alerting tonal signal with an informative visual message or an alerting tonal signal with an alerting and informative speech output.

Generally, the presence of redundant information decreases reaction time (Stroop effect). The robustness of the Stroop effect gives it potential utility in the design of information displays for time-critical real-world tasks in dynamic environments. According to the Stroop effect, non-speech auditory displays in combination with visual displays can be very powerful information transmitters.

For example, a visual warning symbol plus auditory signal will have the advantage of drawing the driver's attention to the warning symbol. Verbal auditory signals used in conjunction with visual signals significantly decreases reaction time when compared to visual signals only. The redundant secondary source of information is integrated with the first to facilitate understanding thereof.

The secondary source of information has to be congruent with the primary source. If tones are not well known they can be misinterpreted and are not necessarily associated with the equivalent visual signals by users. The combined signals using colour, text, audio tone with or without voice messages are most beneficial.

The approach in the aviation environment to use a master alerting signal can be transferred to warning systems in vehicles (see above). A single alerting alarm should be used to draw attention to the potential hazard(s) detected by the warning systems.

The graded sequence of warnings are warnings from mild to severe, e.g. changing the modality. Assuming that the driver has already been alerted by milder warnings, a severe warning is not likely to startle the driver and is thus effective.

13.8 Comparison of warning types, codes and modalities

The comparison of different warning modes becomes more detailed, if type and code of information as well as sensorial modality are taken into account. A series of experiment in a driving simulator and on-road with relevant results for the design of warning modes yielded some conclusive results. When non-verbally-coded objects have to be detected as a secondary task subjects react much more earlier with a combined visual/auditory alarm than with a auditory-only one (see Stroop effect above). With regard to verbally-coded objects, the control error with spoken messages is clearly less than with visual textual messages.

Text is better suited for the spatial information like navigation information, if just one instruction is given and symbols are better if two or more instructions are presented; speech output is the worst. If the code is adapted to the modality, i.e. verbal code for auditory information, added tasks are clearly better performed with speech output. For spatial information which has to be reacted to immediately during driving, the auditory and tactile channels are to be preferred.

In comparison to visual and auditory warnings, tactual warnings of abstract information appears to affect a quicker reaction, especially under conditions of visual, auditory, or combined loading. Warning via the cutaneous sense should, however, not replace the visual and auditory senses, when complex information has to be transmitted rapidly.

The following warning methods are recommended on the basis of these experimental studies: Use immediate dynamic visual signal (blinking) with or without tone for binary, important, time-critical information which seldom occurs. Use visual symbolic or speech output or few text for spatial information.

13.9 Warnings in assistance systems

Assistance systems are systems which help the driver in conducting his driving tasks. ISO/ TC 204/ WG 14 is establishing standards for systems that avoid accidents, increase roadway efficiency, contribute to driver convenience and reduce driver workload. Systems are standardized that contribute to any one or more of the following purposes:

— avoiding crashes;

— increasing roadway efficiency;

— adding to driver convenience;

— reducing driver workload;

— improving the level of traveller safety, security and assistance

by using information about the driving environment to monitor the driving situation, to warn of impending danger, to advise of corrective actions or to partially or fully automate driving tasks. Primary driving tasks, navigation, travel preparation, economy or comfort can be concerned.

Systems for warning of a falling short of a safe distance to the preceding vehicle (or keeping a safe distance automatically) contribute to driving safety and comfort (distance warning systems). The main problem is the warning strategy, which is more important than the actual warning method.

Basically, distance warning systems can communicate the distance below a safe limit by all essential modalities, i.e. visual, auditory and tactile. Different solutions were proposed but there is no conclusive agreement which would be the best mode. Of course, some sort of auditory warning should be included for reasons of alerting.

There is a number of systems for longitudinal support/control, which are in development or have been implemented: Adaptive Cruise Control (ACC), Anti-Collision Systems, Collision Warning, etc. The main purpose of collision-avoidance (or crash-avoidance) warnings is to alert the driver to a hazardous situation requiring some action to avoid a collision. There is a preliminary evidence, that auditory icons, or representational sounds, may be useful as warning devices in vehicles. However, if the users remain sceptical, then a dual-modality display utilizing conventional auditory warnings and a dashboard-mounted visual display might be the best solution for front-to-rear collision-avoidance warnings.

Perspective displays help drivers to maintain larger, safer headway distances during both coupled headway and braking events than when they drove without any display at all. The authors conclude: The combination visual/auditory display had the greatest impact on maintaining of larger, safer headway distances. It helped to increase them significantly when the drivers were coupled with another vehicle, as well as during braking events.

Following human factors guidelines for collision warnings are given: Imminent crash-avoidance warnings must be presented in at least two modes: visual and auditory or tactile, whereby auditory displays are the more important ones. Cautionary crash-avoidance warnings should be presented visually or by means of (less intrusive) auditory or tactile signals. Multiple imminent crash-avoidance warnings should be automatically prioritized in terms of their severity and urgency.

The Standardization Working Draft for PWI 14.5 specifies detailed system requirements and test methods for Side-obstacle warning systems (SOW) including the requirements for the equivalent MMI. At a minimum, the system warning indication shall consist of one of the following: a visual, audible, or tactile warning, whereby several design features are specified. One problem could be driver acceptance with frequent audible or tactile warnings. Detection of sidewards obstacles is better with auditory SOW signals, with or without a visual display. Subjects, however, also accept dash-mounted visual displays.

Well-founded experiences with warning concepts in lane-departure warning systems is already available. A Japanese system combines all three essential modalities, including steering torque which reduces the response time. The time to departure has to be carefully designed, not to bother the driver with too many warnings. The Standardization Working Draft for PWI 14.8 specifies the definition of the system, classification, functions, HMI and test methods for lane-departure warning systems. The human interface requirements will be defined in collaboration with TC 22/SC 13/WG 8, concerning warning presentation, interference effects and specific design features.

13.10 Warning in other applications

The existence of auditory warnings in avionics systems over many years is a hint to consider more auditory warning systems in vehicles. Of course, the situation while flying and while driving is somewhat different. But the basic demand of time-sharing tasks and "online" reacting is comparable. And the noise conditions in vehicles are considerably more suited to auditory signals. However, there are sceptical statements as to the overload with auditory warnings in aircraft, which should also be considered in vehicles.

On the basis of experiences in industrial plants one can forecast some of the problems of alarming in vehicles, even though the time conditions are quite different. These problems may concern a bad consideration of an alarm by the user because of nuisance alarms, high density of alarms and other engineering inadequacies. The different alarm philosophies in industrial plants can give some clues for the design of alarm systems in vehicles, especially with respect to prioritization. Suppression of irrelevant alarms, delay of secondary alarms, grouping of alarms should be considered. It is even conceivable that some kind of acknowledgement of the alarms is introduced. Verification in the car environment means rather to give the driver as detailed information about the underlying problem as necessary to build up a mental model about the problem.

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