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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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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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.

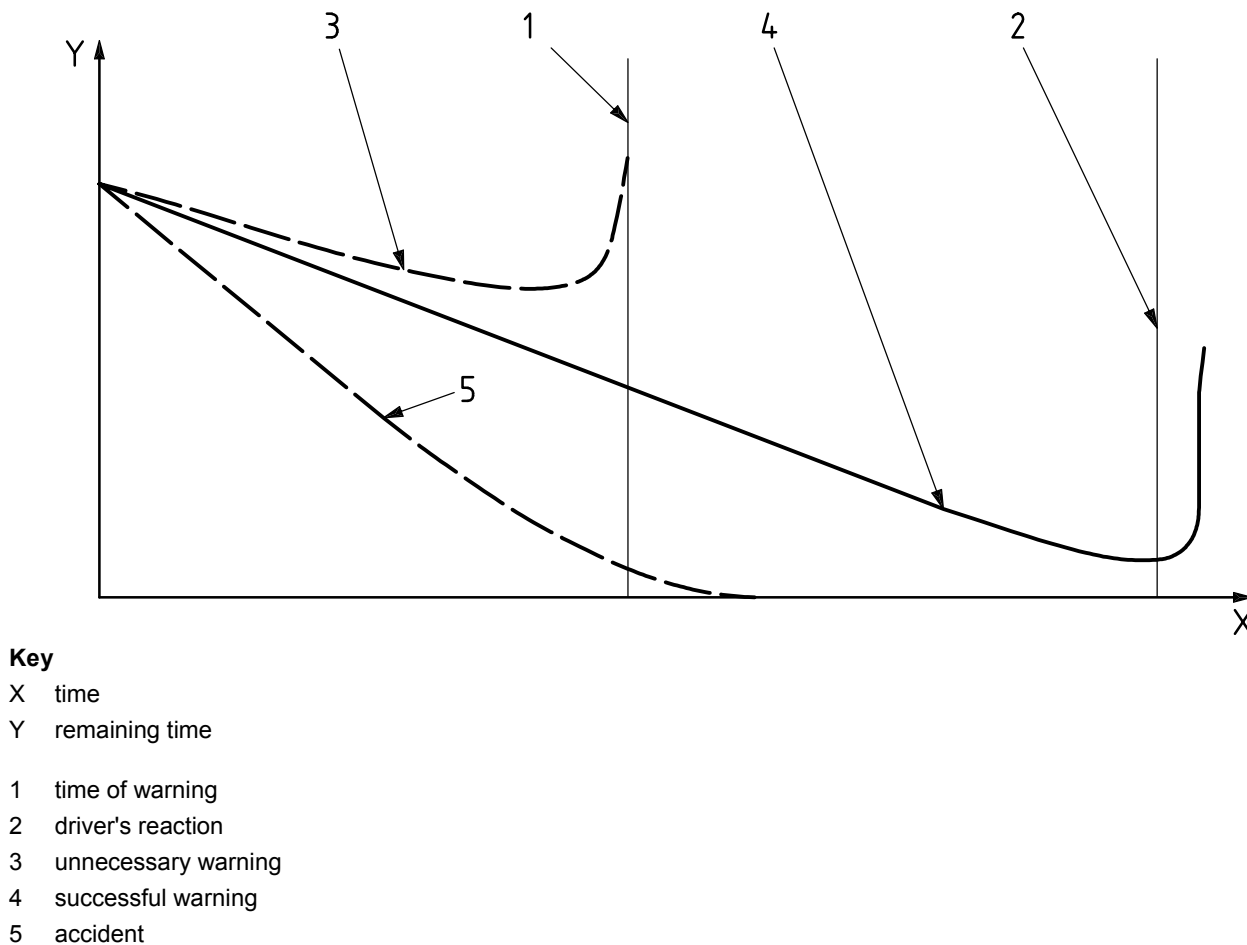


Figure 1 — Time aspects of warning (Kopf, 1998)

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, <i>Ergonomics — System of auditory and visual danger and information signals</i>	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		
	Visual danger signal	Visual warning signal	Visual emergency signal
ISO 11428:1996, <i>Ergonomics — Visual danger signals —General requirements, design and testing</i>	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.

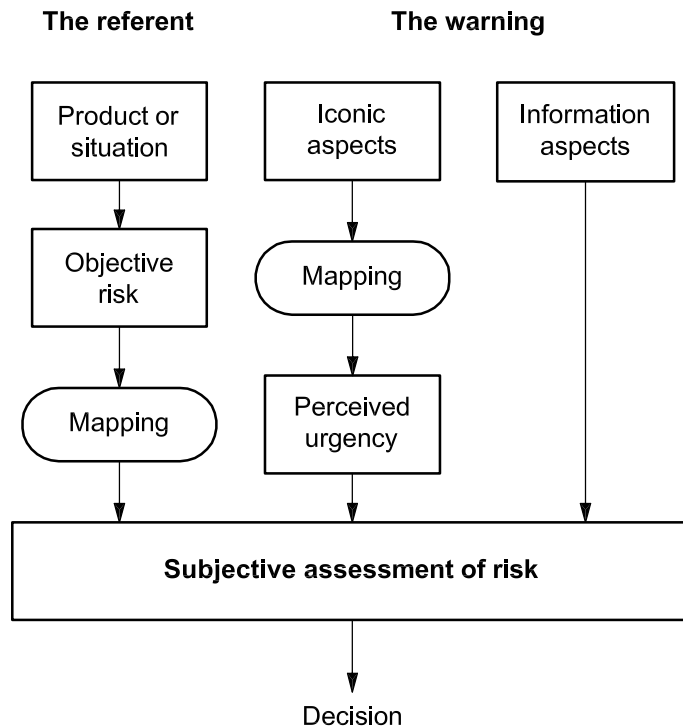


Figure 2 — Components of warning compliance

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 (β) 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 β , 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 utility¹⁾. 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:

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

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, 1998²⁾):

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

- 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).

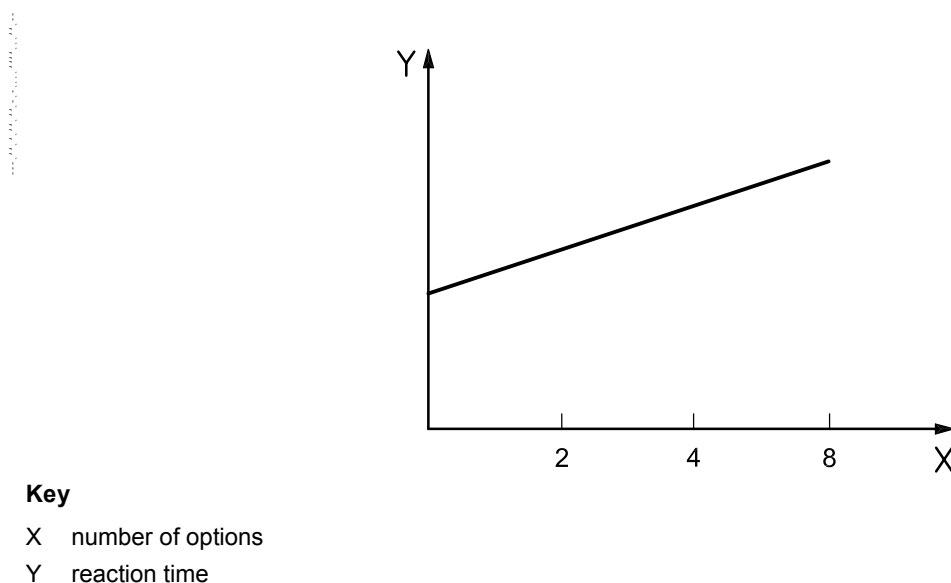


Figure 3 — Reaction time as a function of number of options (Wickens, 1992)

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 compromise 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.

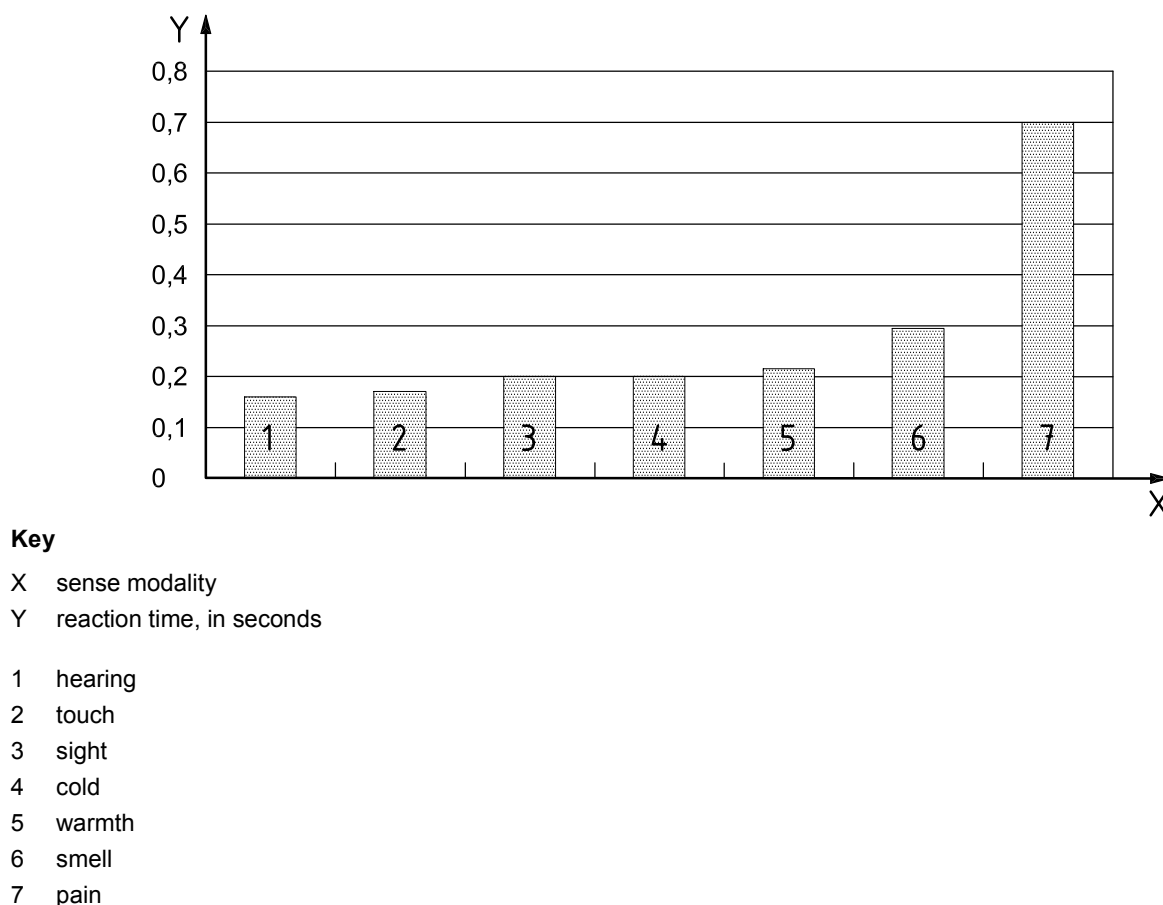


Figure 4 — Reaction times dependent on sensorial modality (Woodson, 1981)

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 comprises 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

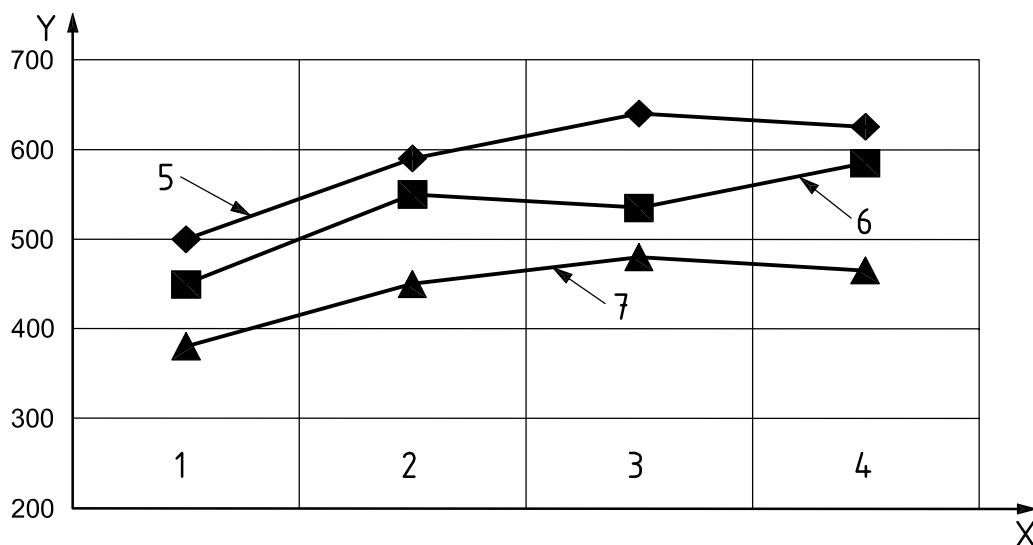
Visual display suited for (needs)	Auditory display suited for (needs)
<u>Information-dependent characteristics</u>	
Many and long messages	Few and short messages
Complex messages	Not too complex messages
Spatial and temporal information	Temporal information
Discrete and continuous information	Discrete 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)
<u>Environment-dependent characteristics</u>	
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
<u>User-dependent characteristics</u>	
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).

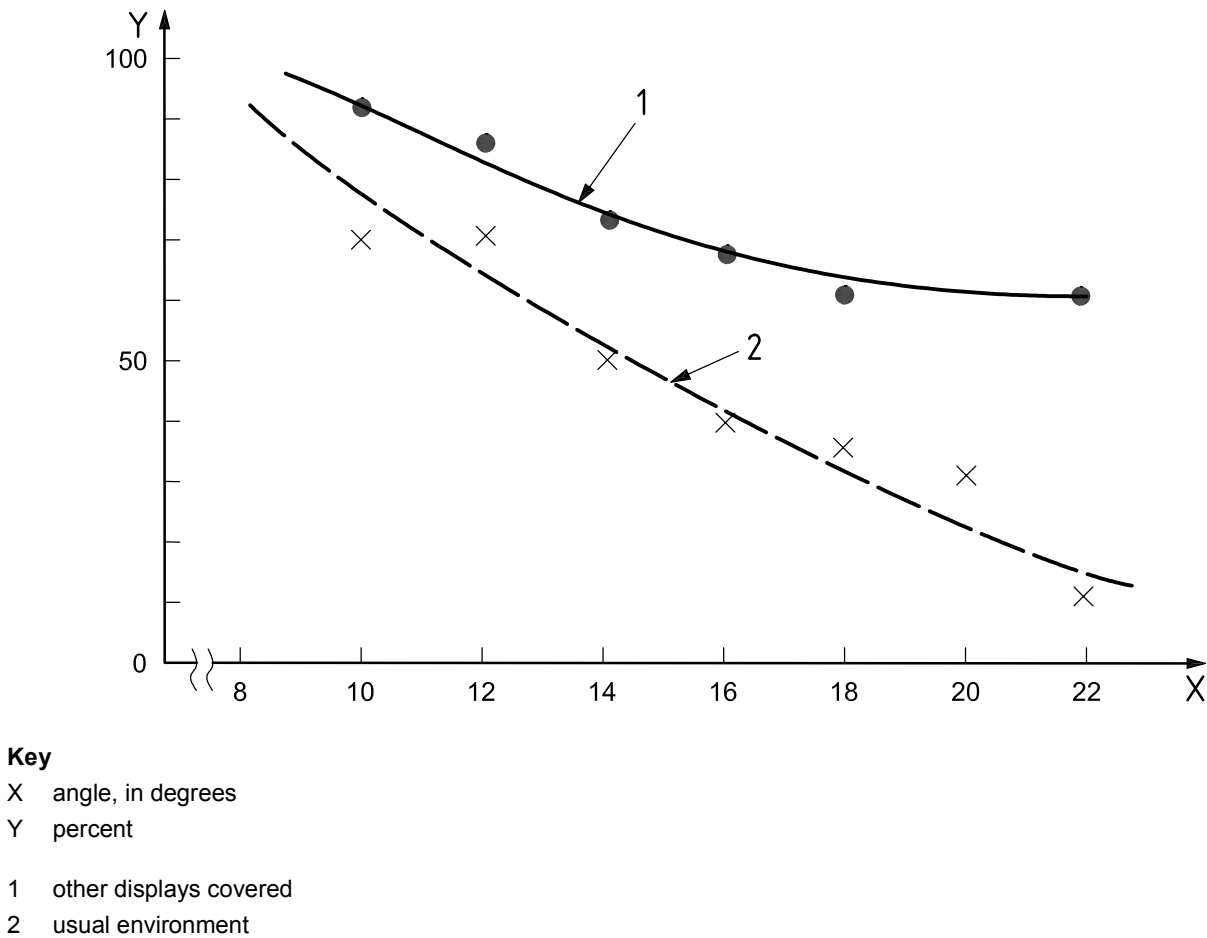


Figure 6 — Peripheral perception of a speedometer pointer (Geiser *et al.*, 1982)

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	+	+	—
Conspicuousness	+	— —	++
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 high⁵⁾. 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;
- synthetic 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).

Radio Volume										
	9.46	6.63	6.58	6.02	5.72	5.17	3.54	2.68	1.62	
Radio Tuning										
	7.02	6.24	4.37	3.96	3.60	2.95	2.36			
Heater										
	9.95	5.61	3.19	3.13	2.74	2.65	2.49	2.41	2.31	
Air Conditioner										
	9.92	4.25	3.69	3.14	2.88	2.78	2.75	2.44	1.83	1.50
Fresh Air Vent										
	8.97	4.37	3.37	3.14	2.96	2.12	1.85	1.31		
Exterior Lamp Failure										
	14.51	10.74	9.48	8.35	4.66	4.06	3.91	3.77	2.68	
Tire Pressure										
	9.55	9.04	6.49	5.76						

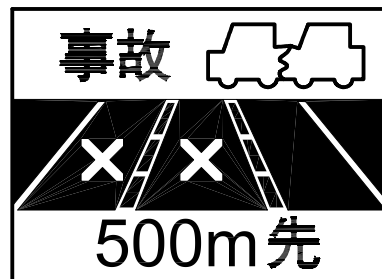
Symbol ratings from Green (1979a)

Figure 7 — Most meaningful symbols in Green (1979)

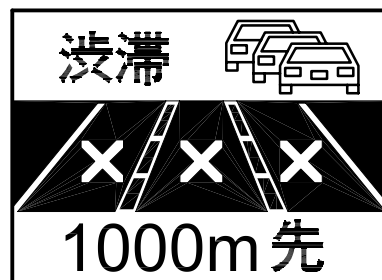
Only a few experiments on symbol learning have been conducted, typically testing factory visitors before and after a tour. In the above-mentioned study of Elsholz and Bortfeld (1978), correct identification of symbols increased from 56 % to 83 %, which shows the potential and necessity of learning the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

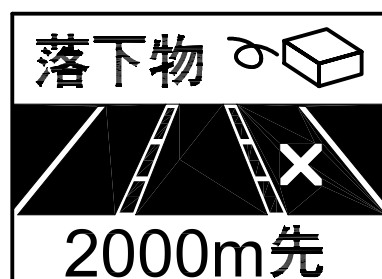
Nakamura (1995) built an experimental warning and information dissemination system. The system provides the driver with the road information detected on the road side and the emergency information received from vehicles to prevent collisions. Sketches of the road ahead with the free and blocked lanes 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.

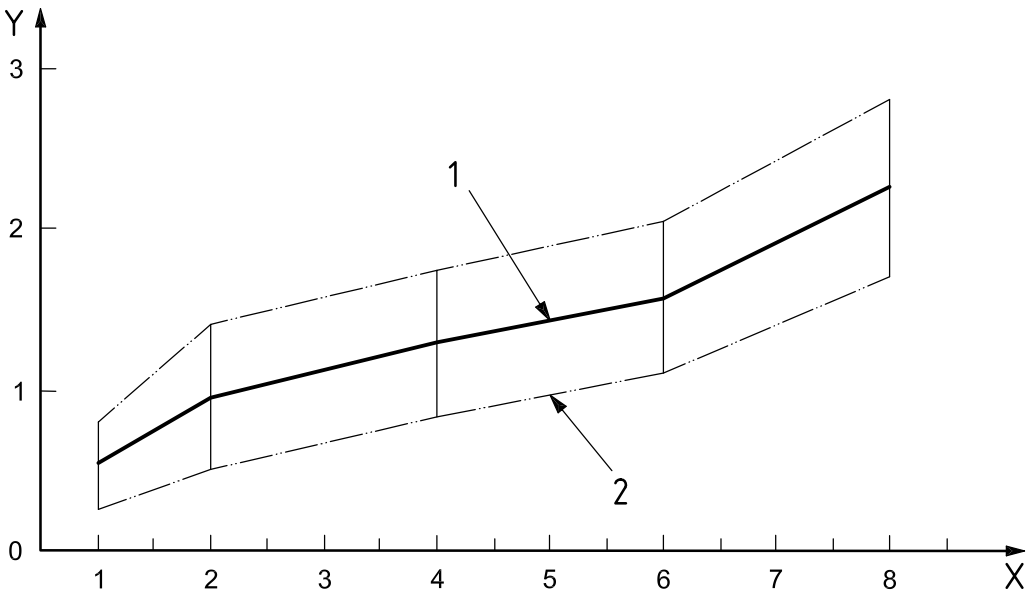
5.3.2.2 Textual warnings

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 authors⁶⁾.

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.

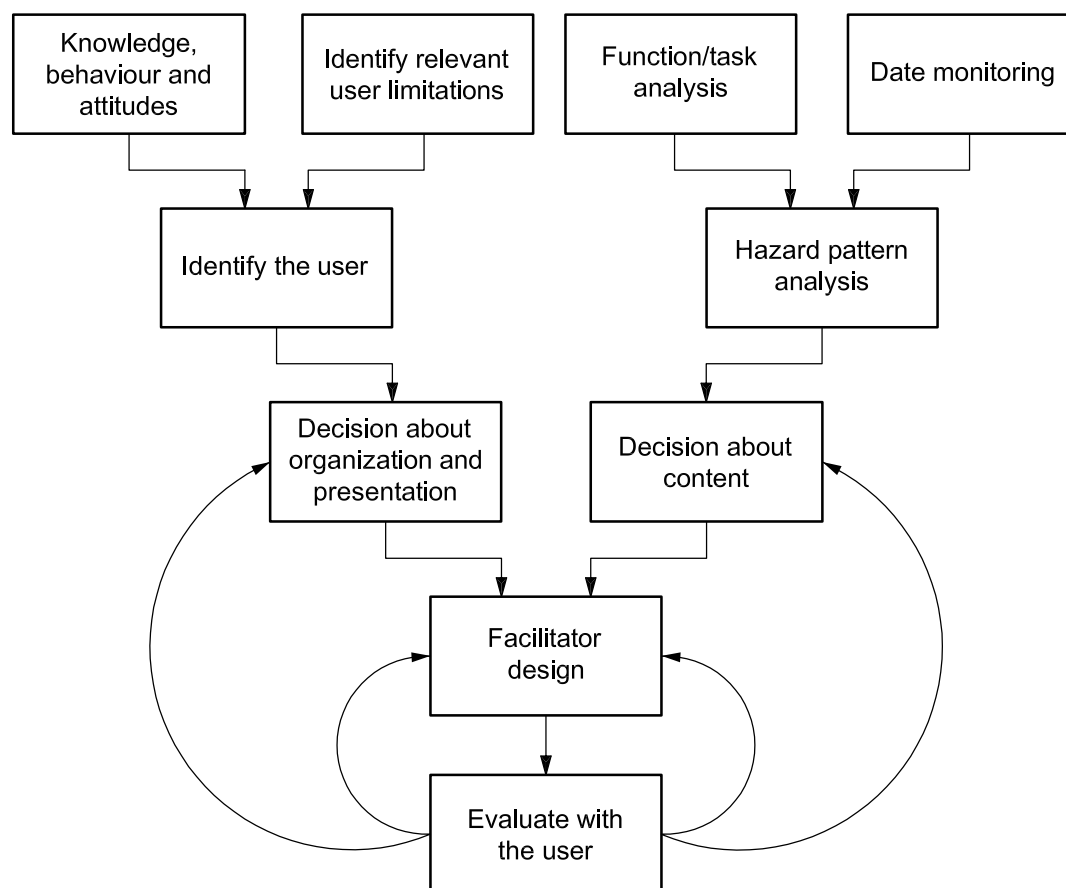


Figure 10 — The facilitator development process (Laux and Mayer, 1993)

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

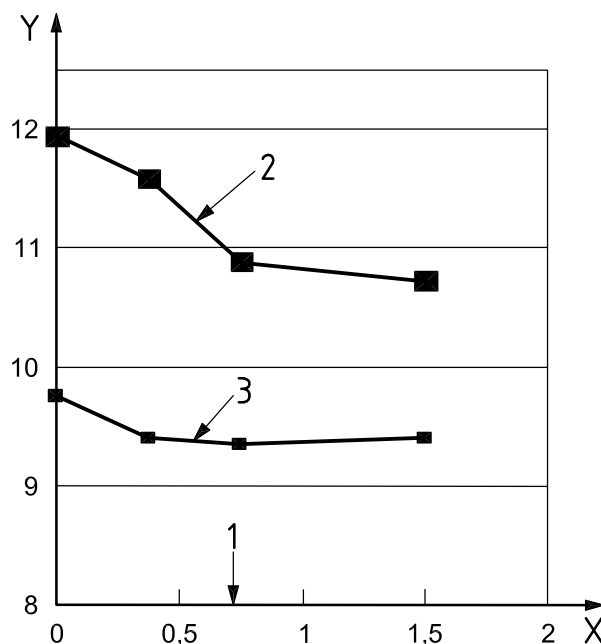
The blinking code consists of a periodical turn on and off of binary signals. It is very conspicuous. Blinking draws the attention of the observer because the eye periphery is very sensitive to brightness changes (Geiser, 1990). Static objects, which cannot be perceived beyond 20° from the main line 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 $\frac{1}{2}$, 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.

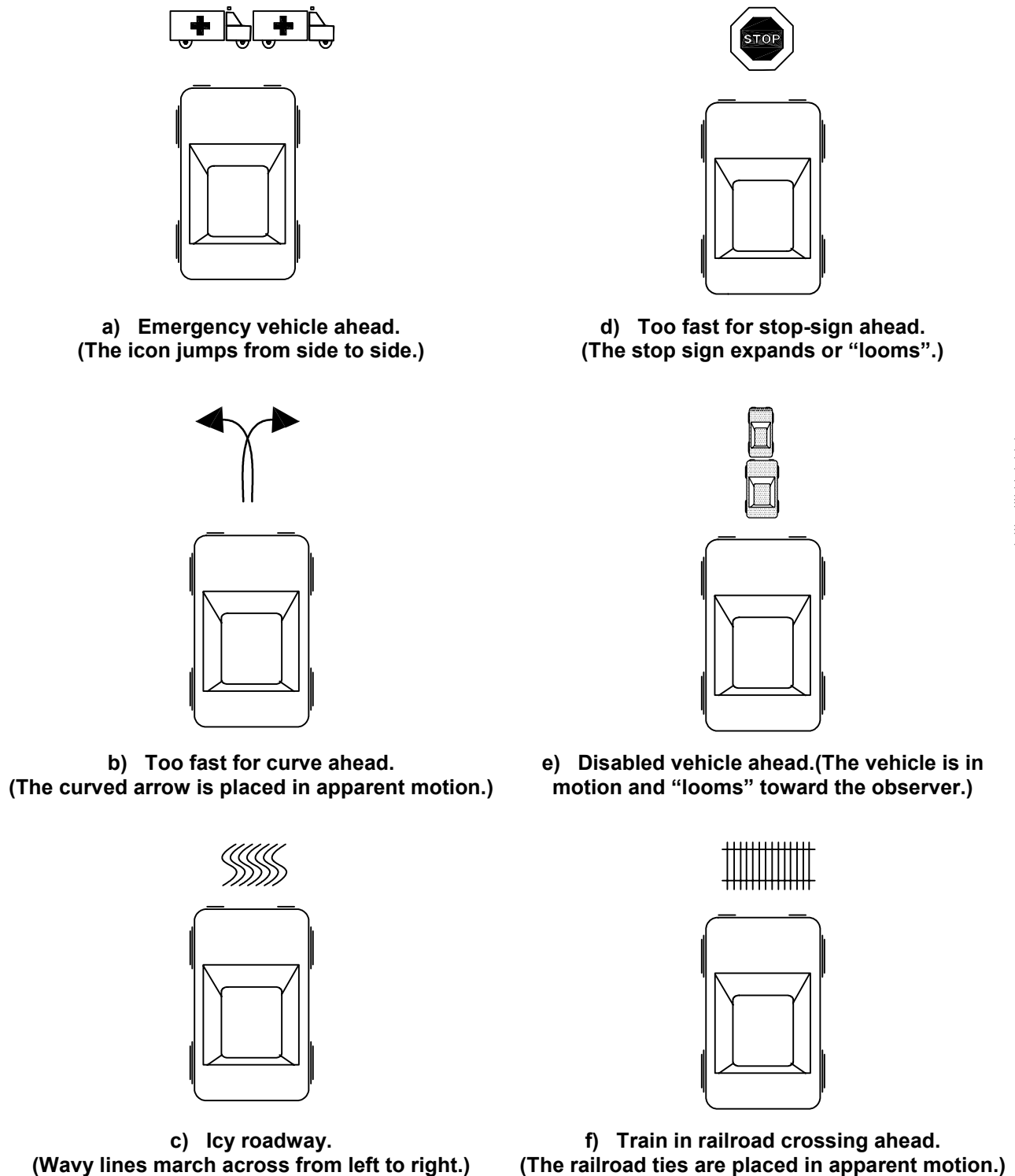


Figure 12 — Moving warning signals (Cohn, 1995)