TECHNICAL REPORT

ISO/TR 16352

First edition
2005-12-01

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

Reference number
ISO/TR 16352:2005(E)

Contents

Page

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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

Introduction

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

a) vehicle control;

b) navigation;

c) collision avoidance.

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

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

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

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

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

1 Scope

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

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

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

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

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

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

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

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

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

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

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

2 Warning signals

2.1 Criteria of warning effects

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

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

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

— recognition of situation;

— evaluation of situation;

— output of warning.

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

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

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

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

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

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

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

— an element which attracts the attention;

— a reason for the warning;

— the consequences if the warning is not observed;

— instruction for actions.

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

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

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

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

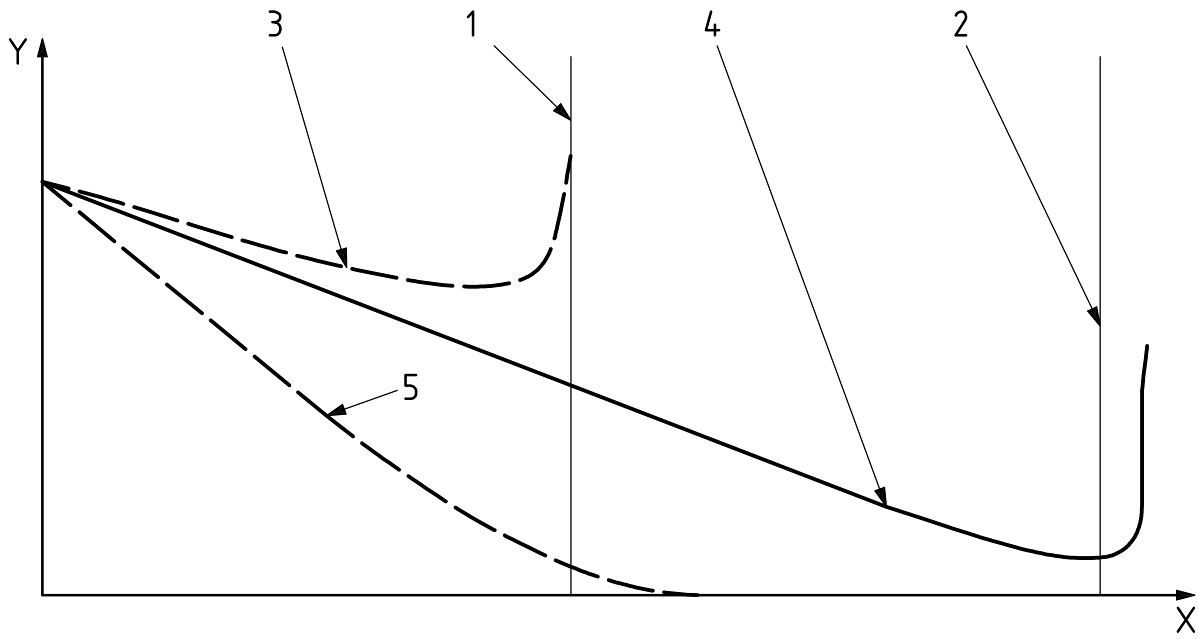
Figure 1 shows the remaining time as a function of time when the warning is successful, not necessary or too late, which results in an accident, depending on the moment of the driver's reaction.

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

— impairment (e.g. startling effect);

— reliable detection and identification (conspicuousness, clearness);

— transformation in safe behaviour.



Key

X time

Y remaining time

1 time of warning

2 driver's reaction

3 unnecessary warning

4 successful warning

5 accident

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

2.2 Categorization of warning signal failure

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

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

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

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

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

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

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

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

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

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

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

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

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

— previous knowledge,

— natural cues from the situation or product, and

— information from the warning.

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

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

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

2.3 Urgency mapping

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

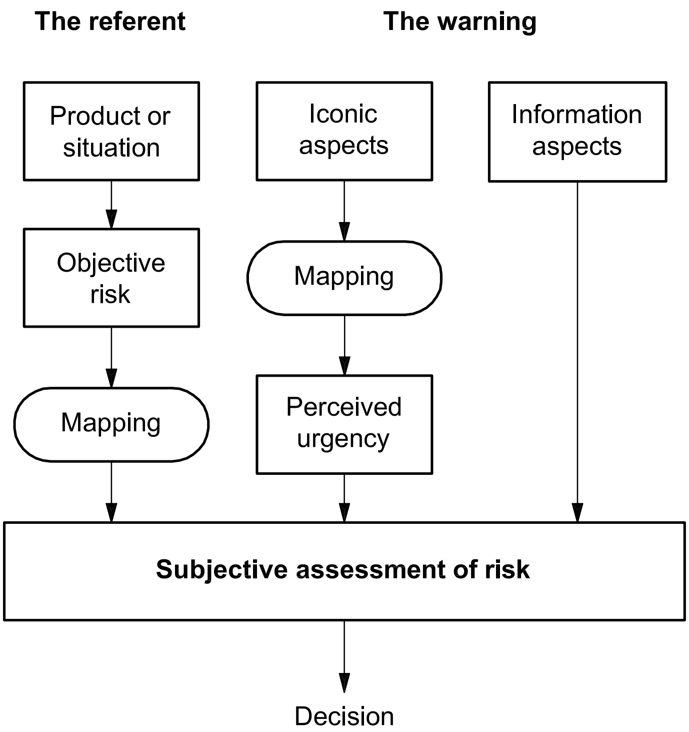


Figure 2 — Components of warning compliance

2.4 Alarm theories

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

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

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

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

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

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

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.