Human factor guidelines for the design of safe in-car traffic information services

Kroon, E.C.M.; Martens, Marieke; Brookhuis, Karel; de Waard, Dick ; Stuiver, Arjan; Westerhuis, Frank; Angelis ,de, Marco; Hagenzieker, M.; alferdock, johan; Harms, Ilse

Publication date:
2019

Human factor guidelines for the design of safe in-car traffic information services

ir. E.C.M. Kroon (TNO), prof. dr. M.H. Martens (TNO), prof. dr. K.A. Brookhuis (University of Groningen), prof. dr. D. de Waard (University of Groningen), dr. A. Stuiver (University of Groningen), F. Westerhuis, MSc (University of Groningen), M. de Angelis, MSc (University of Groningen and University of Bologna), prof. dr. M.P. Hagenzieker (SWOV), ing. J.W.A.M. Alferdinck (TNO), drs. I.M. Harms (Connecting Mobility), drs. T. Hof (DITCM)

NOVEMBER 2019 (3rd EDITION)

rijksuniversiteit groningen

Authors 3rd Edition: K.A. Brookhuis, D. de Waard, A. Stuiver, F. Westerhuis, M. de Angelis

Faculty of Behavioural Sciences
Traffic psychology (Neuropsychology)
University of Groningen
www.trafficpsychologygroningen.info

Index

Contents

Preface

The first version of the "Human factor guidelines for the design of safe in-car traffic information services" was compiled in 2014. In 2016 the guidelines were updated by Connecting Mobility/ DITCM, and the present version is a further update of that version. New systems have been introduced into the marked, and the role of apps on smartphones has increased. This report was updated to include recent developments such as gesture control. The guidelines are aimed at in-car traffic information services.

With more and more guidelines the report has grown and this inevitable makes use for practitioners, be it policy makers, or app developers, more difficult. The ministry asked us to propose a framework, i.e., a flow diagram or app, that would help users to apply the guidelines. The first steps for this tool were taken and these made clear that specifying guidelines and applying these requires interpretation and further specification. For example, if the guidelines state that a navigation system should give route information 36 seconds before action, speed and environment should be taken into account. In a built-up area 36 seconds may be too early or confusing if intersections are at a short distance. It is this type of conflict that makes clear that it is unlikely that this version contains the definitive guidelines.

Dick de Waard, Arjan Stuiver, Frank Westerhuis, Marco de Angelis, & Karel Brookhuis
University of Groningen

1. Introduction

There is a trend to present traffic-related information services more by individual means in vehicles ('in-car') than by collective means on the roadside (next or above roads). Due to this trend, more and also different types of parties will provide traffic information services to the road user via in-car systems and mobile devices.
For traffic safety it is of key importance that in-car traffic service providers take the abilities and capabilities of the driver into account when developing these services. This is because the effect of the services will largely be depending on how road users respond to the information, and therefore also on how these systems are designed and how they interact with the driver. The goal of the guidelines as described in this report is to support in-car traffic service providers with taking the abilities and capabilities of the driver into account. The guidelines are based on the present literature, European standards (such as the European Statement of Principles (ESoP) and the Society of Automotive Engineers, SAE), other guidelines (e.g. NHTSA), expert opinions, and consultations with relevant public and private organisations, both at the beginning of this project as well as at the stage of the concept guidelines.
The starting point of the guidelines is the objective that the information service does not give rise to potentially hazardous driving behaviour. All criteria pursue this objective, which means that the criteria are interdependent. That is, a bad performance on one criterion may be detrimental to the performance on other criteria and the overall service. With that, it is not only important to design for safe use by the driver using the service, but also to take the behaviour of other (non-equipped) road users into account. An advice or warning may seem in the best interest to the driver, but it may undermine traffic safety due to the (absent) reactions of other road users. It is important to realise that a traffic information service will operate in the complex and dynamic traffic environment.
The guidelines are developed for services that support the driver in his or her driving task, and distinguishes safety-related warnings and non-safety related information (such as navigation advice and some driver behaviour feedback apps). The guidelines are not written for apps that provide entertainment, since it is the believe that, in general and at the moment, such systems are not reconcilable with safe execution of the driving task. Though, knowing that advertisement cannot be outlawed, it is important to understand the basic principles of these guidelines to minimise the safety risks that distraction by such messages may cause. For instance, these messages should only be given when driver's workload is low and should have the lowest priority (in comparison to information related to the driving task). Furthermore, these guidelines are based on standard devices, currently available. Not all new developments, such as head-up displays, and head-mounted displays will bring new design possibilities, which are fully covered by the current criteria yet. However, in the present version some of these developments, e.g. gesture control, has been added.

The guidelines are divided in two sections. The first section is on human factors criteria, describing aspects of the service that determine how distracting or effortful the interaction is for the driver. These guidelines explain the criteria and provide some examples per criterion to illustrate their application in practise. Topics that will be covered are related to driver workload, timing of a message, information priority, distraction, validity, recognisability, acceptance, physical interaction and possible side effects. The second section is on ergonomic criteria, focussing on issues such as legibility and audibility of the information. These criteria are more or less self-explaining and do not require additional information. Therefore examples will not be provided in the second section.

2. Human Factors Criteria

The most relevant human factors criteria are summarised below, stating per criterion the main rules of thumb. This list, based on the 10 golden rules of human factors [51], provides an overview of the main points of attention which an in-car information service should meet. The following sections of this chapter elaborate on the human factors criteria in more detail, providing background information on the origin of the rules of thumb and practical examples.

Additional workload

Additional workload (task load) must be limited.

- Information can be presented best when the workload of driving itself is low. See section 2.1 for a definition of high and low workload.
- In complex situations, e.g. when the infrastructure is complex, and/or traffic density high, information provided to the driver should be minimised; only urgent messages should be issued.
- Human-machine interface elements that have complementary or interdependent functions should be grouped and presented together to support user perception [2].

Timely presentation

Information should be presented in a time window when the information is relevant and allows time to respond to. Not too late, not too early.

- Information should be presented preferably about 36 seconds before the point of action or 200 m before the first road sign. This point is mostly relevant or the motorway, where speeds are higher and distances between situations (e.g. exits) are large enough to be able to inform the driver 36 seconds in advance. In built-up areas the distances between situations (e.g., intersections) is much smaller. As an example, travelling the distance between two intersections that are 200 metre apart, at a speed of 50 km/h, takes only around 14 seconds.
- Information should be presented minimally 9 seconds before the point of action.
- Information which is always of (high) relevance to the driving task can be displayed best continuously at a fixed position on the screen.
- Information with high priority should be presented as close as possible to the expected driver's field of view [46].

Priority by context and urgency

Information is prioritised by importance to the driver in relation to the context and urgency.

- Safety related warnings have priority over non-safety related information.
- In case of a safety critical situation, a multi-modal and multi-stage warning strategy should be adopted [68]. That is, change modality as the severity and urgency of the situation increases [45].
- Drivers should always have the option to turn off or disable non-safety related information [44].
- Drivers should be able to adjust warning intensity, volume. [45].
- Information that requires behavioural change, e.g. speed adaptation because of congestion, has priority over information that does not.
- The in-car information device should display high-priority messages easily distinguishable from low-priority information [46].

- Information that is related to operational and manoeuvre control has priority over information related to the strategic, navigation level of the driving task (see Annex 1 for the explanations on the three levels of the driving task).

Visual attraction
Visual distraction from the driving task should be prevented.

- Information that is presented should not lead to glances that exceed 2 seconds eyes off the road. The cumulative time spent gazing away from the roadway should not exceed 12 seconds [44].
- Visual content that causes a startle response should be avoided.
- The display should not present more than four separate types of information units simultaneously in relation to an event, next to the continuously shown navigation information.
- Visual interfaces should be positioned within a 30-degree cone with respect to the driver's normal line of sight [31].

Auditory attraction
Auditory distraction from the driving task should be prevented.

- Safety related warnings should always be combined with an auditory attention cue.
- A ‘neutral’ auditory sound should be used when warning for hazardous situations rather than emotion-laden sounds.
-

Vibrotactile attraction
Vibrotactile distraction from the driving task should be prevented.

- Information should be provided within a signal frequency between 150 and 300Hz at all body locations to ensure optimal sensitivity [10].
- Vibrations should not be shorter than 50ms or longer than 200ms [50].
- Vibrotactile stimuli should be adapted to the urgency of the message (with as result that imminent vs cautionary vs notification messages can be distinguished) [46].
- To distinguish messages, vibrotactile variations should differ in terms of location and timing rather than frequency and amplitude [41].

Ambiguity, validity and reliability
Information presented should be non-ambiguous, valid and reliable.

- Information presented should not be interpretable in multiple ways.
- The occurrence of false alarms and misses should be minimised, to ensure reliable information.
- The content of the information should be relevant and in line with the traffic scenario at that moment in time to be able to respond to if required.

Recognisability and consistency
Information should be recognisable and consistent with legal traffic signs and signals and local road side information.

- In-car information should be in accordance with local road side information, discrepancies between different information resources should not occur.
- The traffic information service should use the formal national signs and signals of the local country (no modifications) or signs and signals that are commonly accepted as well as standardized symbols (if available, there is a need for more standardization [27]).

- Where information is provided through non-standard symbols, additional text or vocal phrases should be added [61]. Text and sound should be displayed in the driver's preferred language.
- The use of abbreviations should be kept to a minimum, especially for safety-critical information.
- It is recommended to provide text as intuitive as possible, avoiding long messages[2]. In this case long means more than 30 characters (without punctuation) [44].

Credibility, acceptance and compliance

- Credible information is highly accepted and increases compliance.
- Dynamic information provision such as a sudden speed limit change or closing of a traffic lane should be accompanied by an argument.
- Information should make sense in the situation, not conflicting with perceived feasibility.

Physical interaction

- Physical interaction with the driver should be minimised.
- The information service should not require any manual control input from the driver while driving.
- In case any manual control input is requested, the driver should be able to keep at least one hand on the steering wheel while performing a secondary task.
- In case any manual controls are located on the steering wheel, the specific command should not require concurrent use of both hands.
- Upon request of the driver, it should always be possible to turn the application off, to adjust the brightness of the screen and tune the volume. Furthermore, operating buttons should require minimal visual guidance.
- A non-native display should always be fixed to the car with a holder or located there, preferably in 10 to 20 cm reach of the hand. This choice lies often with the drivers themselves however.
- The control activation feedback should be immediate and clearly noticeable (e.g. click, vibrate).

Negative side effects

- The information service should minimise negative side effects, for example, an advice should not lead to higher speeds, and particularly avoid large speed differences between different drivers (maximum 20km/h differences in operating speed).
- Route planning should avoid routing through city centres, school areas and other safety critical areas (if they are not the final destination).

System Guide

- An in-car information system supplier should provide a concise description of the main system purpose, the design of the interface, its benefits and limitations
- The system device should clearly state how and when drivers can use it and when they cannot.
- The driver should be able to be aware of the current status of the device or at least know the meaning of displayed signals when the system is activated.

2.1. Additional workload

Limit additional workload

The driving task is a task that can be quite loading for a human being, but at other times it can also be monotonous. Additional task load, for instance having to process a visual, auditory or tactile message, may add considerably to the varying workload of driving in difficult driving conditions. In scientific terms it concerns a secondary task in addition to the primary task of safely driving the car. Provided that the driving task has priority over other tasks at all times, the time for processing messages, including execution should be kept as short as possible and low-demanding to prevent overload. Drivers should always be informed and aware of the risks associated with the secondary task, even if they are already accustomed to doing so while driving [45, 39]. For the task load of the primary task, the complexity of the situation is very important (the complexity of the situation is also important for the criterion 'Timing of a message'). The complexity of the situation depends amongst others on the complexity of the infrastructure, traffic density and the speed that is being driven as well as weather conditions. Driver state (e.g., fatigue), together with the just mentioned task load, determine workload.

For example, with increasing speed, task load of driving and the amount of information that needs to be processed within a given time frame increases accordingly. As a result the corresponding spare capacity for a secondary task decreases. And vice versa of course, which might even lead to favourable effects of a secondary task in case of a long tedious primary task, e.g. driving on a quiet road with low traffic density for a long time.

In general, it is advisable to develop an in-vehicle information device where functions which are not relevant or should not be used by the driver while driving, should be made inaccessible while the vehicle is in motion. The supplier is encouraged to provide a clear warning regarding the negative consequences associated with the use of the device while driving and to make a clear statement on how the driver retains responsibility for his or her actions and compliance with traffic rules [4, 61]. Services should be confined to information providing messages, being more or less task-relevant. Actions such as gaming, using social media, skyping, using WhatsApp etc. are undesirable. Experience may have a positive effect in the sense that task load is not as high for an experienced driver than for a novice driver. The effects of ageing can be twofold, on the one hand older drivers are experienced drivers, on the other hand cognitive processing may slow down. In general messages should preferably also be adapted for the ageing driver, to enable adequate processing and allow safe driving.

Example 1. *Adjustable settings* Some car manufacturers today lead the way by designing and developing driving aid devices to provide information in such a way that their target groups (e.g. solvent, often elderly drivers) are offered more tuning adaptations such as larger font, more time to process the messages, navigation based on arrows only etc. So, the settings of a service provider can be standard initially, but should in principle be adaptable. Adapting the interface should be made transparent and easy to use for the user.

Example 2. *Workload related settings* Some apps or services have a 'Driving mode' that should switch on when used in the car. This means that while driving, specific items or actions cannot be performed while driving. A more advanced option would be that in the vicinity of complicated road networks (large junctions), less information is provided, or information is provided in a simpler way with less details.

2.2. Timely presentation

Information should be presented in a time window when it needs to be processed and can be acted upon

Route guidance has a long history, from indicator stones along the roads in the Roman Empire to modern digital navigation systems. TomTom starts 2km before a required action (and when referring to a distance they refer to the end of an exit), while Rijkswaterstaat starts 1200 m before, referring to the start of an exit or in case of a weaving area to the end of the weaving area. The Rijkswaterstaat distances are tuned to the standard cruise speed at 120 km/h on motorways, which is 36 seconds when converted to time. Information regarding route choices should be provided at least 200 m before the first route guidance sign (allowing time for reading the normal road guidance signs). Position and timing are based on an optimum across the motorway user, allowing sufficient time to read and process all the information and to make a decision and act; this requires about 36 seconds as a starting point for a navigation message. It leaves sufficient time to change traffic lane(s) in time in high traffic density. Note that providing a message rather late may lead to dangerous driving behaviour by drivers who still try to follow up on the advice but do not succeed (or succeed by performing risky behaviour). It is advised to provide a message at least 9 seconds before the start of the off ramp. On the other hand, providing information too early may be perceived as a false alarm by drivers and lead to confusion, which undermines the acceptance (see also criteria on valid and reliable information and acceptance). Besides, when providing road side information in-car, it is strongly advised to match the timing (see also criterion on consistency and recognisability). It has to be stressed that the above timing applies to motorway driving, not to driving in a built-up area where intersections can follow quickly after each other. With 100 metres separation and a driving speed of 30 km/h, the 100 metres are covered in 12 seconds. Obviously, timing needs to be different here.

In contrast to route guidance messages, the time range of safety related warnings varies more, depending on the content of the message. Preferably the message is also given early, but a (repeated) warning close to the situation or event is also important. As opposed to navigation messages, safety related warnings that alert the driver (and provide an advice on the control level of the driving task, see Annex 1) should always been given since they require less time to be processed and executed. For example, collision alerts seem to be more effective if designed in a multi-stage mode. Being warned in advance favours an adaptation of driving behaviour to the critical situation ahead, thus reducing stress responses. At the same time, early safety-related messages may also be interpreted as false alarms if the critical situation has mitigated itself when arriving at the situation. In fact, there is a compromise between giving drivers adequate time to prepare for the traffic scenario and the risk of being intrusive and unnecessary. A multi-stage warning can overcome these risks by extending the range of early warning signals to higher levels of caution when an immediate reaction by the driver is foreseen to avoid a safety critical situation [65]. From initial results published, there is a linear relationship between the speed difference and the distance to the safety-critical scenario. In other words, the more one expects a critical scenario, the greater the distance from which to activate the early warning signal. This relationship is influenced by the difference in speed between vehicles on the road: the smaller the difference, the smaller the distance from which to activate the signal [65]. Other information is continuously relevant to display, such as the maximum speed at that road section. However, in case of high priority (safety) messages, it is advisable to give them priority at certain moments (see criterion about priority). Also relevant for the timing of a message is the location and traffic situation, i.e.

the point in time of the start of message presentation in relation to sharp curves, high traffic densities or even the presentation of two simultaneous messages (then priority has to be assigned to the most important message that should obviously be provided first). This presupposes a lot of information about the direct environment, but in a modern car this information can be made available (e.g., via extended maps). In complicated situations, for example, a blind bend or high traffic density, workload for safe driving may easily increase (see also criterion about workload) up to a point that messages should not be given unless very urgent. However, route guidance information should always be provided, but it may be provided earlier if the driver is approaching a complicated situation or workload is expected to be high. Less urgent messages should be postponed.

Example 1. *Stranded lorry* Urgent message: suppose the driver approaches a stranded lorry, situated just after a blind bend in dense traffic, the message "leave the right traffic lane / stranded lorry ahead" is provided further ahead than in case of a normal lane change advice. If there is a delay in the information provision, it is given even while entering the curve; all other messages are suppressed.

Example 2. *A too late navigation message* Advising the driver to take the exit while he is already passing it, may lead to dangerous driving behaviour by the driver who still might try to take the off ramp. On motorways the information is preferably provided 200 m before the first route guidance sign of 1200 m.

Example 3. *Wrong way driver* It is hard to accurately predict the location of a wrong way driver, since this information is often based on limited reports of other road users and changes rapidly. A safety related warning is therefore provided to all road users in a wide range (e.g., 30 km area circular around the location), who (may) come across the wrong way driver.

2.3. Priority by context and urgency

Information is prioritised by safety criticality to the driver in relation to the context and urgency

Priority is defined by:

- Relation to change in behaviour Information that relates to acute required changes (such as speed adjustments or lane changes) gets priority over information not directly related to driving behaviour (such as delay due to traffic congestion).
- Relation to the strategic, manoeuvre, control (operational) level of the driving task (see Annex 1) and urgency. Generally speaking, information with respect to the manoeuvre/control level (e.g., lane changes) gets priority over information with respect to the strategic driving task (e.g., route changes) and information at the control level (e.g., braking) gets priority over route information or lane changes.
- Relation to safety. Safety related warnings and advises have priority over general information with respect to the manoeuvre/control level.

Only one message at a time should be presented and not too soon after one another (see for details criterion on visual distraction), since this is detrimental for drivers' comprehensibility and increases distraction and workload (see criteria related to distraction and workload). As already mentioned in the previous paragraph (see criteria on timely presentation), in the case of a safety related message, a multi-stage strategy is advisable. Users seem to prefer being informed first of the expected critical situation, followed by an early warning signal which then becomes more and more acute as the distance from the risk is getting shorter. It might also be useful to give the driver the option to turn off or disable non-safety related information [44] and adjust volume and brightness [45].

In addition, presenting information that is not related to the driving task is therefore highly discouraged as well. This type of information should be presented while being stationary (e.g., at a petrol station or while parked). Safety warnings should only be presented if the scenario requires a behavioural change of the driver or if raising alertness is needed directly. The following lists indicate the priority of safety warnings and non-safety related information. Please note that the priority of a warning also depends on how close one is to the actual hazard. This means that distance to the hazard has priority over the hazard in itself. Exception here is wrong-way driver since the exact location of the hazard cannot be determined, so this always has the highest priority.

Safety related warnings[1]

a) Wrong way driver

b) Unprotected accident area

c) Animal, people, obstacles, debris on the road

d) Slippery road

e) Unmanaged blockage of a road

f) Reduced visibility

g) Exceptional weather conditions

h) Short-term road works

i) Unexpected end of queue

j) Protected accident area

Non-safety related information

a) Navigation

b) General traffic information

c) Feedback and advice on traffic flow (e.g., speed and lane advice to pass a traffic light at green) or eco-friendly driving (to reduce fuel consumption)

d) Fuel advice (e.g., advising the most favourable petrol station on the route, etc.)

Example 1. *Slippery road*

A safety warning is suddenly activated, such as a slippery road ahead. This slippery road warning temporary mutes the route navigation messages (sound) as long as a driver is not required to take action. If a driver is required to take action, the two warnings should be played after one another: "In 600m, take the exit on the left, warning, slippery road". The symbol for slippery road can remain to be displayed on the screen as long as this message is valid.

Example 2. *Traffic delay*

[1] Warnings a) to h) are described in the European regulation No886/2013. Warnings i) and j) are added since they are also used in practice.

If information, in addition to the navigation screen, about a traffic delay is presented in the navigation screen, these messages should disappear if a safety related warning is activated. The safety message has priority and in order to avoid too many messages on one screen non-safety related information should disappear, see also the criterion on visual distraction (2.5).

2.4. Visual attention

Visual distraction from the driving task should be avoided

Visual signals must be applied with great care as the visual channel of the driver is already heavily engaged in the primary task of driving. This means that the visual signals must be readily seen, recognised and understood without negatively interfering with the driving task. For this purpose, there are several characteristics that can be defined to improve and maximise the visibility, readability and comprehensibility of the message, for example, features such as the type of display, use of touchscreen, use of colour, size and spacing of the text (see also ergonomic criteria).

Visual information should not lead to a situation in which drivers take their eyes off the road for longer than 2 seconds. Driving with the eyes off the road for longer than 2 seconds has been shown to lead to increased crash risk and hazardous situations ([34]).

Messages should not contain animations, moving images or alternating messages. Presenting animations or alternating (text) messages will attract attention from drivers and distract them from the driving task. Drivers are curious to see what will come next and will continue looking at the screen to see the next part of the animation or message. As a result drivers may take their eyes off the road for too long. In general, it is also suggested to avoid a cumulative time spent gazing out of the roadway for more than 12 seconds [45].

Emotional content should be avoided. From research on distraction by commercial billboards along the road it is known that drivers react slower to traffic signs, brake harder and look longer away from the road, when the message has emotional content. Especially negatively emotional content, such as showing the consequences of an accident, is highly distracting. As a result drivers pay less attention to the relevant aspects of the road environment. Positive emotional content, such as romantic pictures, is also distracting, though to a lesser extent.

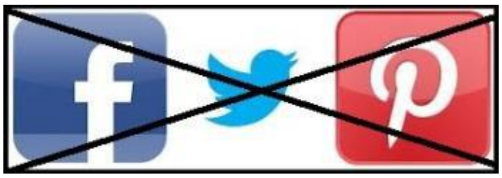
For safety-related messages, continuous or graded displays can be helpful in facilitating driver’s situation awareness (e.g., for imminent forward crash warnings [23]). In general, critical visual messages should be placed within 5 degrees of the driver's field of vision, while warning displays should not exceed 15 degrees [45].

The display should not present more than four separate types of information units simultaneously in relation to an event, next to the continuously shown navigation information. Other information, not relevant to this event, should be suppressed. Too many different types of information cannot be read and processed within a few seconds, and will be distracting to drivers. Upon request of the driver, messages can also be spoken out loud to minimize visual distraction.

Commercial messages should be avoided while in driving mode.

Example 1. *Social media*

Messages that are continuously provided by other (non-traffic related information) applications and thus not directly relevant for the driving task, should be switched off while driving.



This should be done automatically, if a device is mounted and/or put in driver-mode ('safe'). For instance, social media messages and applications are often not designed for safe usage while driving. While driving, these messages should be blocked by the traffic information service or a safe user mode should be activated (e.g., messages are spoken out loud).

Example 2. *Road work warnings*

Information, additional to the navigation screen, should not contain more than four information units. A safety warning on road works may therefore contain a speed sign, road works warning sign, an indication of the road layout and distance.

2.5. Auditory attention

Auditory distraction from the driving task should be avoided

In case of hazardous situations and safety warnings directly relevant for the driving task, visual information should always be combined with an auditory attention cue. Acoustic signals can help the driver to understand the critical scenario on the basis of the urgency (i.e., criticality of the situation), of the place from which it comes (i.e., where the danger is expected) and of the semantic meaning (i.e., information on the situation and on the necessary actions) of the signal itself. In general, acoustic signals work better as imminent warnings than as general or non-urgent information alerts. This is because acoustic signals are perceived more as acute, sometimes even annoying and cognitively demanding. In order to prevent the driver from turning off the acoustic signals entirely, it is essential to consider the linear relationship between urgency and annoyance of sound. As the acoustic signal increases in frequency, intensity or volume, the greater the possibility of being perceived as urgent and less as annoying.

A 'neutral' auditory sound should be used when warning for hazardous situations rather than emotion-laden sounds (such as exclamations). Drivers receiving auditory (spoken) route guidance, show better lane keeping behaviour and report less workload compared to visual route guidance.

A neutral alert sound preceding a risky situation leads to a reduction of the speed without affecting lateral position, and may help drivers to look at relevant areas of their visual field. It is important to make sure that there is no confusion among the various signals in the vehicle's auditory repertoire . Sounds associated with acute alarms such as sirens used by emergency services (police, ambulance, fire brigade) are not neutral and should therefore not be used. Loud sounds may cause startle reactions, therefore simulated traffic horns and honking sounds should also be avoided. Semantic urgent warning signs (such as the word: Danger) at a moderate noise level (70 dB) and less urgent signals (such as the word: Pay attention) at higher volume (85 dB) were found to be effective in reducing the risk of a (simulator) accident. Sounds should not exceed an intensity of 90 dB [45]. It could be of help to discriminate cautionary warnings from imminent warnings based on the urgency, intensity, and frequency of the auditory signals as follows [45]:

For cautionary warning use	***For imminent warning use***
Lower urgency characteristics	Higher urgency characteristics
Continuous tone	Intermittent with short intervals
Low signal repetition rate	His signal repetition rate
Low intensity	High intensity
Pleasant, ''friendly'' sounds	Obtrusive sounds
Gradual onset and offset rates	Rapid onset/offset rate (but not enough to startle)

Example 1. *Mute sound warnings of non-driving related apps*

Some apps that inform and/or provide warnings on incoming email or weather alarms combine these messages with auditory sounds. This mode should be switched off during driving since auditory warning sounds should only be used in hazardous situations.

Example 2. *Continuously changing information*

A sound related to continuously changing information, as expected traffic delay and current speed limit, is highly distracting and interferes with the important warnings. These messages should not be used in combination with auditory cues.

2.6. Haptic attention

Haptic distraction from the driving task should be avoided

There are two types of haptic interfaces, vibrotactile and kinaesthetic interfaces. The first provides information through vibrations in physical contact with the driver and is usually included in seat belts, the steering wheel or the touchscreen. The second type excerts forces on limbs or affects body motion, e.g., counter-force applied to the accelerator pedal.

From preliminary research on haptic signals, it is concluded that information should be provided within a signal frequency range between 150 to 300Hz for all body sites to ensure optimal sensitivity [10]. The optimal vibration frequencies are reported to be between 200 and 250 Hz. Vibrations should not be shorter than 50ms or longer than 200ms, adapting them to the urgency of the message in such a way that for example imminent, cautionary and notification messages can be easily distinguished [46]. To distinguish messages, vibrotactile variations should differ in terms of location and timing rather than frequency and amplitude.

2.7. Ambiguity, validity and reliability

Information presented should be non-ambiguous, valid and reliable

Care has to be taken that information is clear, as ambiguously formulated information can (by definition) be understood in multiple ways. This may lead to confusion by the driver and unsafe driving behaviour. In case the message contains a (safety) advice, the message should clearly communicate what is going on, why an advice is given and what (behaviour) is expected from the driver. Only when there is no time for additional information, the safety warning should only present what is expected from the driver, without an explanation. High reliability is crucial for acceptability and road safety. It is therefore important that there are no false alarms (a message when there is no issue, e.g., a traffic queue warning system providing a warning for congestion under free driving conditions) and no misses (no message when there is an issue, e.g., a road works warning system does not report a roadwork zone). False alarms and misses decrease trust and the willingness to comply and lead to de-activation of the system in the longer term. Drivers' trust can be safeguarded if the safety system provides a follow-up feedback after the alarm has been activated but the danger is no longer present [45]. Furthermore, the content of the message should be relevant and in line with the traffic scenario at that moment in time. In case speed limits and other roadway traffic signs are shown in-car, the limit or sign should only appear at the moment where the limit or traffic sign is actually valid. So, it should not be active before or after the road section at which it applies. It is strongly recommended to assess the reliability and validity of the system before the system launching. Note, reliability is a point of interest for the service providers as well as the government; the latter is responsible for providing correct and timely information in the first place (see Nationaal Wegen Bestand).

Example 1. *Signs may be ambiguous in their context*

Indicating a traffic jam sign with a speed limit might mean that this speed limit is due to a traffic jam ahead, or that this speed limit tries to prevent the occurrence of a traffic jam. The message does not clearly communicate what's going on and why the advice is given. Using the same traffic jam sign in both scenarios may undermine the credibility of the advice. In this case, it is advised to use the formal traffic jam sign to indicate and warn for an existing traffic jam ahead.

Example 2. *Validity of a message*

If a lane or motorway exit is blocked, an advice to follow this lane or take this exit is not valid. The information service should advice a different lane or exit and provide an alternative route in case this is necessary. In addition, when this information is not relevant to the driver because he takes an off ramp earlier, this information should not be provided at all.

Example 3. *Avoid exceptions and clarifications that may lead to more confusion*

This sign tries to communicate a complex message, containing two specifications about the speed limit. First of all, the message is complicated in itself and secondly, the speed limit outside this range is implicit (130, this is not explicitly mentioned). It is not clear to drivers what is expected of them. In addition, the two specifications might be interpreted in multiple ways. This leads to confusion and larger variations in speed, which is adverse to traffic safety. Due to these comprehensibility problems, these road signs are no longer used. In-vehicle systems should always provide the speed limit that is valid at that specific moment in time at that specific location.

2.8. Recognisability and consistency

Information should be recognisable and consistent with legal traffic signs and signals and local road side information

80 or 90 km/h?

Not only should the information itself be easy to understand, it is also important that in-car information is in accord with local road side information. Discrepancy between roadside information and in-car information may lead to confusion and might be perceived by the driver as incorrect, undermining the perceived reliability of the service. High consistency is especially important when the information concerns legal traffic signs and signals. It may have a detrimental effect on traffic safety if drivers are advised incorrectly with respect to legal limits and traffic regulations. If the posted information on site deviates from the in-car presented information this is confusing and attention capturing. This problem may easily happen if speed limit information in the vehicle is based on obsolete maps. In the Netherlands, the traffic information service should use the formal Dutch national signs and signals if applicable. Although a foreign driver may encounter signs that are not used in his/her home country, providing the local signs in-car is to be advised. The chance of errors increases when local signs need to be translated into signs and symbols of the driver's home country. Text messages may be displayed in the driver's preferred language. In addition, no new signs or signals should be "invented". Only if current traffic signs and signals are not applicable, a new sign may be introduced after proper testing for the self-explaining character in user tests.

Example 1. *Signs when driving in The Netherlands* A foreign driver is provided with a Dutch warning sign in The Netherlands, though the explaining text is in his own language. A driver can set his/her own language preferences in the settings.

Example 2*. Displaying routes in-car*

Routes should be displayed resembling the signs used on the roadside, for example, in the Netherlands direction signs are white on blue and detour signs are black on yellow, whereas in Germany normal direction signs are black on yellow.

Example 3*. Speed limit*

Displaying a speed limit should be in accordance with the general symbol for speed limits. The bad example in the image shows an undesirable modified version. By modifying the symbol, the sign becomes more difficult to interpret and affects the legibility. Is it 50 km/h over 1000m or during the upcoming 1000m? Also, the red border is smaller and the font for the 50 is also different than the 50 used on traffic signs. If one wants to display this kind of additional information (e.g. "in 1000 m" or "during 1000 m") one should display this on a separate sign below the speed limit sign.

2.9. Credibility, acceptance and compliance

Information is credible and aims for high acceptance and compliance

Whether a message in a certain situation is accepted by the driver depends on how the message is perceived given that situation. If the driver completely agrees with, or endorses the underlying principle or reason behind the message, compliance is high. However, compliance is not necessarily a direct consequence of acceptance and credibility, though good acceptance and high credibility certainly help. If a message is not credible but the inherent measure is visibly enforced (by the police), acceptance will be low, but compliance is highly likely. To create or enhance acceptance of messages and advice, solid arguments should be given why this specific behaviour should be adapted if it deviates from normal command and prohibitory signs. For normal prohibitions and commands (such as an overtaking ban in a curve or a speed limit at the entrance of a village) no extra explanation or argument is needed. However, dynamic information such as a sudden speed limit change or closing off a traffic lane should be accompanied by an argument. The trustworthyness of the underlying argumentation is related to or is even conditional to complete acceptance of messages and advices. In particular prohibitions or commands that may seem inconsistent or illogical to the road user, should be presented in the order that is most convincing. The driver should have a feeling of feasibility of the commanded behaviour, it must be practicable.

Not trustworthy messages with respect to a certain ordered behaviour will quickly lead to an interpretation of false alarm, if not properly argued.

Pure information provision, for example “For Dam Square, turn right in 600m”, needs not to be argued.

Example 1. *Compliance*

Advice to keep right without an explanation will result in a lower compliance. If the reason is not made clear, drivers are less inclined to follow up on the advice. When explaining that a traffic lane is closed, for instance due to road works, drivers will understand the importance of the advice.

Example 2. *Trustworthiness*

Suppose the speed limit is decreased, but no explanation is given, the trustworthiness will be low and compliance is quickly gone. This is disastrous for that specific spot and the effect could easily spread out. When this speed limit is accompanied by an explanation such as “urban area”, acceptance and compliance by drivers will be higher. Also, when presenting a speed limit with the explanation ‘smog’ on a clear day, trustworthiness is also affected and compliance will be low, although the advice may be correct as smog is not always clearly visible and noticed by drivers.

2.10. Physical interaction

Physical interaction with the driver should be minimised

The information service should not require any manual control input from the driver while driving. This means that there may be manual interaction with the system on the initiative of the driver, but the system should be able to function properly without the driver’s response. Physical interaction while driving results in reduced attention to the road, which potentially results in a decrease in driving performance. This is due to physical as well as visual and cognitive distraction. Therefore it is important that default settings are consistent with drivers’ needs and preferences. However, upon request of the driver, it should be possible to turn off the application, to adjust the brightness of the screen and tune the volume. These may be adjusted by the driver with a simple interface, but preferably brightness and volume are adjusted automatically to the changing surroundings (like darkness in tunnels). In case any manual control input is requested, driver should always be able to keep at least one hand on the steering wheel while performing the secondary task. Also if manual controls are located on the steering wheel, the specific command should not require concurrent use of both hands. Some preliminary results suggest the use of touchscreens which appear to be preferred by drivers and are less demanding than rotary and steering controls [38]. This probably depends on the (input-)task and will be different in other contexts. More research is needed on this topic.

Preferably, a driver should only operate a simple button in case the system desires input by the driver, for instance a ‘yes’ or ‘no’ button. Though, with the remark that the corresponding message is easy to comprehend and the whole exercise does not lead to more than 2 seconds eyes off the road (see criterion on visual distraction). If the display is not located within reach of the driver, hazardous situations might arise if the driver wants to control the system. Hence, put controls within easy reach. Reach envelopes for drivers are specified in SAE Standard Driver Hand Control Reach (SAE J287). Other relevant information appears in SAE J1138. Research on driver reach preferences shows that preferred ranges are 4 to 8 in (10 to 20 cm) which are less than the maximum envelopes in the standards and recommended practices.

For safety reasons, the display should always be fixed to the car by means of a holder. Recommended is to place the display at dashboard level (see picture), to ensure that the display is not blocking the view of the driver.

Example 1. *No input necessary*

When drivers are asked whether they would like to take a shorter alternative route, with a yes/no button. Preferred: no input is necessary; the driver sees the options and chooses by following the directions he prefers.

Example 2. *Extensive menu*

Service gives the driver the opportunity to mark an incident or police surveillance, though the option menu is extensive with long and uninterruptible sequences of manual-visual interactions to indicate the type and location of the incident. If this input cannot be simplified, this should not be a feature of the service at all.

Example 3. *On/off button*

A system should have a clear on/off button at a fixed spot.

2.11. Negative side effects

The service avoids negative side effects

Advice should not have substantial negative side effects on any of these traffic related outcomes. With regard to safety, it should be avoided that the advice will lead to higher speeds Apart from larger impact in case of a collision, higher driving speeds also provide less time to process information and to act on messages or instructions, and increasing the braking distance. Therefore the possibility of avoiding a collision is smaller.

The information or advice should not lead to large detours away from motorways to less safe roads. Driving more kilometres will lead to more crashes and unwanted environmental effects. Moreover, not all roads are equally safe. Motorways are the safest roads. In the Netherlands, most fatalities occur in crashes on urban and rural roads with speed limits below 90 km/h. Generally speaking, the number of fatalities per distance travelled by motor vehicles on motorways and trunk roads has been shown to be around four times lower than on roads with a speed limit of 80 km/h. In addition, city centres, school areas and other safety critical areas should be avoided (unless the final destination).

Example 1. *Avoid abrupt behaviour*

Do not warn for speed checks at the very last moment (< 100 m or < 3 seconds) because this can cause abrupt braking reactions (see also criterion on timing).

Example 2. *Encourage smooth driving*

An application that encourages drivers to accelerate in order to get the green light just in time would lead to undesired behaviour from both a safety as well as an environmental perspective. On the other hand, a good example would be informing the driver about green lights coming up with an advice to choose a smooth and constant driving speed that will lead to drive through the green traffic lights. Such smooth driving behaviour can be beneficial for safety, environment and traffic flow.

Example 3. *Erroneous information*

Erroneous information regarding the current speed limit – either too low or too high – can result in large speed differences on the road between those who rely on the advice provided by the application compared to those using the signs along the road.

3. Ergonomic criteria

Brightness and contrast of the system are adjustable to ambient lighting conditions. In addition, contrast ratio is between 3:1 and 10:1

When the brightness and contrast of the system are not adaptable to the ambient light conditions (day/night), this could result in blinding and/or difficulty to read the message. It is desirable that brightness and contrast are automatically adjusted to match the ambient. In addition, contrast is easily adjustable by the driver while driving, with a very simple gesture (preferably turning knob on side of display). In general, a contrast ratio between foreground and background between 3:1 is considered acceptable, but an higher contrast is recommended. A contrast ratio of 5:1 is preferred, especially in night mode [46].

Font type, size and spacing should be easily legible from the driver's seating position (taking into account different age groups)

The font should be simple and clear to facilitate easy reading. Font size should be determined by the distance between the eyes and the screen, and a minimum visual angle of 12° (20° is recommended), even though earlier guideline suggest a greater height of 24° [46]. Possible crowding effects should be taken into account. This may occur due to words and symbols that are located too close together. As a result visual clutter may occur. The human factors literature shows that differences among modern font types have less impact on legibility (readability) than physical characteristics such as size or contrast. Nevertheless, plain font types (such as Arial, Geneva and Helvetica) are more legible than ornate ones (such as London), especially for short messages or single words. Where in-vehicle displays are compared with external displays (e.g., highway signs), it is desirable that the font types be similar. Research has also focused on defining stroke-width and character height standards to guarantee sufficient legibility (i.e., the easiness in identifying and understand a character or a symbol). Initial results suggest to use larger stroke and character width, when the information is more critical. The ratio between stroke width and character height should be between 10% and 20% whereas the ratio between character width and height is set between 65% and 80% [30].

Use words of maximum 10 letters and no more than 2 lines of 4 to 5 words per message, confining reading to 2x2 seconds maximum

Long messages may result in too much distraction, since drivers keep their eye off the road for too long. See also criterion on visual distraction in the previous chapter. Previous guidelines suggest to display not more than four units of information in a single in-car device message.

The auditory volume level of the system should be adaptable, but never higher than 115 dB

The volume of the system should be loud enough to overcome background noise, though not too loud to be a cause for driver distraction or startle the driver. Pitch (increase) may emphasize a message, but only to be used temporarily. Research claims maximum volume levels of 95 dB-115 dB. It is desirable that the volume level is automatically adjusted according to the background noise. Volume level should be easily adjustable while driving with a very simple interface, preferably one touch on a touch screen or by means of a knob on the side of the display. In addition, it is preferred that the volume level is about 15 dB above ambient noise.

Colour use should be in line with drivers' expectations and general colour use in traffic. For colour blind people use redundant colour coding or colour combinations that are visible for them

Colour use is closely related to comprehensibility. In order to facilitate quick recognition of the signs provided, they should be designed according to the standard colour coding of road signs. It is desirable that no more than 5 colours are used in the design (incl. black and white). The NHTSA, instead, suggests to use only 4 colour codes [45]. Naujoks suggests to use no more than 5 colours (excluding white and black) [46]. The colours selected to communicate with the driver should be in accordance with typical stereotypes and common scenarios. For example, red is commonly accepted to report the presence of an imminent danger or a critical situation, orange-yellow to activate a state of alert and green to assure the driver of the absence of danger. Moreover, there are some colour contrast combinations that should be avoided because they are detrimental to convey the message (i.e. green/red, green/blue, yellow/red, yellow/blue, violet/red)

For colour blind people extra design rules should be observed, first of all, relaying also on aspects other than colour to convey critical messages (i.e. text messages, auditory signals). In the Netherlands, about 1 out of every 12 men and 1 out of every 200 women has a colour deficiency. The vast majority has a congenital type of red-green colour blindness. To provide for colour blind people, use redundant colour coding, i.e., support the colour coding with additional information of a different type (e.g. shape, position, size, text, sound) which is directly linked to the colour. For example, the red traffic light is always on top. Furthermore, use an orange-red colour instead of red as an alarm signal and a bluish-green colour instead of green as "safe situation" signal. Part of the colour blind people (protanopes) perceive a red colour as black, therefore they are unable to see red coloured objects on a black background. The use of an orange-red colour overcomes this.

Information presented should make use of abbreviations as little as possible

Abbreviations often take more time to be comprehended by the driver and can be quickly misunderstood when the explaining context is minimal. Commonly known abbreviations that can be used are km/h, m, min and s. The use of abbreviations for safety-critical situations should be avoided.

4. References

1. Aarts, L. & van Schagen, I. (2006). *Driving speed and the risk of road crashes: A review*. Accident Analysis & Prevention, 38, 215-224.
2. AdaptIVe Consortium, 2017. *Final functional human factors recommendations (D3.3).* Retrieved from: http://www.adaptive-ip.eu/index.php/AdaptIVe-SP3-v23-DL-D3.3-Final%20Functional%20Human%20Factors%20Recommendations_Core-file=files-adaptive-content-downloads-Deliverables%20&%20papers-AdaptIVe-SP3-v23-DL-D3.3-Final%20Functional%20Human%20Factors%20Recommendations_Core.pdf
3. Ahlstrom, V., & Kundrick, B. (2007). *Human Factors Criteria for Display: A Human Factors Design Standard Update of Chapter 5.* U.S. Department of Transportation. Federal Aviation Administration. DOT/FAA/TC-07/11.
4. Alliance of Automobile Manufacturers (AutoAlliance). (2006). *Statement of principles, criteria and verification procedures on driver interactions with advanced in-vehicle information and communication systems ,including 2006 updated sections* (Report of the Driver Focus-Telematics Working Group]. Available at www.autoalliance.org/index.cfm?objectid=D6819130-B985-11E1-9E4C000C296BA163
5. Biondi, F., Rossi, R., Gastaldi, M., & Mulatti, C. (2014). *Beeping ADAS: reflexive effect on drivers' behavior.* Transportation Research Part F: Traffic Psychology and Behaviour, 25, 27-33.
6. Bliss, J.P., & Acton, S.A. (2003). *Alarm mistrust in automobiles: how collision alarm reliability affects driving.* Applied Ergonomics, 34, 499-509.
7. Brookhuis, K.A. & de Waard, D. (2000). Assessment of drivers' workload: performance, subjective and physiological indicators. In P.A. Hancock and P.A. Desmond (Eds.) *Stress, Workload and Fatigue*. Mahwah, New Jersey, U.S.A.: Lawrence Erlbaum Associates.
8. Brookhuis, K.A., de Waard, D., & Janssen, W.H. (2001). Behavioural impacts of Advanced Driver Assistance Systems – an overview. *European Journal of Transport and Infrastructure Research*, 3, 245-254.
9. Chattington, M., Reed, N., Basacik, D., Flint, A., et al. (2009). *Investigating driver distraction: the effects of video and static advertising.* RPN256. Transport Research Laboratory TRL, Crowthorne.
10. Choi, S., & Kuchenbecker, K. J. (2013). Vibrotactile display: Perception, technology, and applications. *Proceedings of the IEEE, 101*(9), 2093–2104.
11. CIE (2001). *Colours of light signals* (Standard CIE S 004/E-2001). Vienna, Austria: International Commission on Illumination CIE.
12. De Waard, D. & Brookhuis, K.A. (1999). Driver support and automated driving systems: acceptance and effects on behavior. In M.W. Scerbo and M. Mouloua (Eds.) *Automation Technology and Human Performance: Current Research and Trends*. Mahwah, N.J., USA: Lawrence Erlbaum Associates.

13. De Waard, D., Van Der Hulst, M., & Brookhuis, K.A. (1999). Elderly and young driver's reaction to an in-car enforcement and tutoring system. *Applied Ergonomics*, 30, 147-157.
14. Dingus, T. A., McGehee, D. V., Manakkal, N., Jahns, S. K., Carney, C., & Hankey, J. M. (1997). Human factors field evaluation of automotive headway maintenance/collision warning devices. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 39, 216-229.
15. Dingus, T.A., Klauer, S.G., Neale, V.L., Petersen, A., et al. (2006). *The 100-car naturalistic driving study, phase II; Results of the 100-car field experiment*. DOT HS 810593. National Highway Traffic Safety Administration NHTSA, Washington, D.C.
16. Di Stasi, L.L., Contreras, D., Cañas, J.J., Cándido, A., et al. (2010). The consequences of unexpected emotional sounds on driving behaviour in risky situations. *Safety Science,* 48, 1463-1468.
17. Edquist, J., Horberry, T., Hosking, S. & Johnston, I. (2011). Effects of advertising billboards during simulated driving. *Applied Ergonomics,* 42, 619-626.
18. Elvik, R. (2009). *The Power Model of the relationship between speed and road safety: update and new analyses.* TØI Report 1034/2009. Institute of Transport Economics TØI, Oslo.
19. Elvik, R., Christensen, P. & Amundsen, A. (2004). *Speed and road accidents; An evaluation of the Power Model.* Institute of Transport Economics TØI, Oslo.
20. European Union (2007). *Commission Recommendation of 22 December 2006, on safe and efficient in-vehicle information and communication systems: update of the European Statement of Principles on human machine interface.* Official Journal of the European Union.
21. Fallon, C. K., Murphy, A. K. G., Zimmerman, L., & Mueller, S. T. (2010, 17-21 May 2010). *The calibration of trust in an automated system: A sensemaking process.* Paper presented at the 2010 International Symposium on Collaborative Technologies and Systems.
22. García, E., Blanco, R. Nogueira, A. & Rial, M. (2013). *Usage of a Driving Simulator in the Design Process of new HMI concepts for eco-driving Applications* (eCoMove project). HFES Europe chapter, Torino.
23. General Motors Corporation & Delphi-Delco Electronic Systems. (2002). Automotive collision avoidance system field operation test, warning cue implementation summary report (Report No. DOT HS 809 462). Washington, DC: National Highway Traffic Safety Administration.
24. Green, P. (2008). *Driver Interface/HMI Standards to Minimize Driver Distraction/Overload*. Michigan, University of Michigan Transportation Research Institute
25. Guo, F., Klauer, S., Hankey, J., & Dingus, T. (2010). Near crashes as crash surrogate for naturalistic driving studies. *Transportation Research Record: Journal of the Transportation Research Board*, 2147, 66-74.

26. Hallen, A. (1977). *Comfortable Hand Control Reach of Passenger Car Drivers*. SAE paper 770245, Warrendale, PA: Society of Automotive Engineers.
27. Helman, S. & Carsten, O. (2019) What Does My Car Do? Parliamentary Advisory Council for Transport Safety, PACTS, UK.
28. International Standards Organization (1977). *Road Vehicles—Passenger Cars—Location of Hand Controls, Indicators and Tell-Tales (International Standard 4040)*. Geneva, Switzerland.
29. International Standards Organization (2009). *Road vehicles -- Ergonomic aspects of transport information and control systems -- Specifications and test procedures for in-vehicle visual presentation (International Standard 15008)*. Geneva, Switzerland.
30. International Standards Organization (2011). *Road vehicles -- Ergonomic aspects of transport information and control systems -- Specifications for in-vehicle auditory presentation (International Standard 15006)*. Geneva, Switzerland.
31. Japan Automobile Manufacturers Association. (2004). Guideline for in-vehicle display systems, Version 3.0. *Japan Automobile Manufactures Association*.
32. Jeong, H., & Green, P. (2013). SAE and ISO standards for warnings and other driver interface elements: a summary. Technical Report UMTRI-2013-16, February 2013. Retrieve from: https://deepblue.lib.umich.edu/bitstream/handle/2027.42/134039/103248.pdf?sequence=1&isAllowed=y
33. Khastgir, S., Birrell, S., Dhadyalla, G., & Jennings, P. (2017). Calibrating trust to increase the use of automated systems in a vehicle. In N. A. Stanton, S. Landry, G. Di Bucchianico, & A. Vallicelli (Eds.), *Advances in Human Aspects of Transportation: Proceedings of the AHFE 2016 International Conference on Human Factors in Transportation, July 27-31, 2016, Walt Disney World, Florida, USA* (pp. 535-546). Cham: Springer International Publishing.
34. Klauer, S. G., Dingus, T. A., Neale, V. L., Sudweeks, J.D., & Ramsey, D. J. (2006). *The Impact on Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data* (Report No. DOT HS 810 594*).* Washington, DC: National Highway Traffic Safety Administration.
35. Kloeden, C.N., McLean, A.J., Moore, V.M. & Ponte, G. (1997). *Travelling speed and the risk of crash involvement. Volume 1: findings.* Report CR 172. Federal Office of Road Safety FORS, Canberra.
36. Kloeden, C. N. & McLean, A.J. (2001). Rural speed and crash risk. In *Road Safety Research, Policing and Education Conference Proceedings*, 18-20 November 2001, Melbourne, Victoria, Australia, Vol. II. Melbourne: Monash University, 163-168.
37. Kloeden, C.N., McLean, A.J. & Glonek, G. (2002). *Reanalysis of travelling speed and the risk of crash involvement in Adelaide South Australia.* Report CR 207. Australian Transport Safety Bureau ATSB, Civic Square, ACT.
38. Large, D. R., Burnett, G., Crundall, E., Lawson, G., Skrypchuk, L., & Mouzakitis, A. (2019). Evaluating secondary input devices to support an automotive

touchscreen HMI: A cross-cultural simulator study conducted in the UK and China. *Applied ergonomics*, *78*, 184-196.

39. Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 46*, 50-80.
40. Megías, A., Maldonado, A., Catena, A., Di Stasi, L.L., et al. (2011). Modulation of attention and urgent decisions by affect-laden roadside advertisement in risky driving scenarios*, Safety Science,* 49, 1388-1393.
41. Meng, F., & Spence, C. (2015). Tactile warning signals for in-vehicle systems. *Accident Analysis & Prevention, 75*, 333–346.
42. Michon, J.A. (1985). A critical view of driver behavior models: what do we know, what should we do? In L. Evans & R.C. Schwing (Eds.), *Human behavior & traffic safety*. New York: Plenum Press.
43. National Highway Traffic Safety Administration, NHTSA (2013). Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices. Department of Transportation, Washington, D.C., Federal Register, Vol. 77, No. 37, February 24, 2012. Accessed 120226 at http://www.gpo.gov/fdsys/pkg/FR-2012-02-24/pdf/2012-4017.pdf
44. National Highway Traffic Safety Administration, NHTSA, 2014. Visual-manual NHTSA Driver Distraction Guidelines for in-Vehicle Electronic Devices (2014). Docket no. NHTSA-2014-0088, National Highway Traffic Safety Administration, September 2014.
45. National Highway Traffic Safety Administration, NHTSA, 2016. Campbell, J. L., Brown, J. L., Graving, J. S., Richard, C. M., Lichty, M. G., Sanquist, T., ... & Morgan, J. F. (2016). Human factors design guidance for driver-vehicle interfaces. *Report No. DOT HS*, *812*(360), 252.
46. Naujoks, F., Wiedemann, K., Schömig, N., Hergeth, S., & Keinath, A. (2019). Towards guidelines and verification methods for automated vehicle HMIs. *Transportation research part F: traffic psychology and behaviour*, *60*, 121-136.
47. Nilsson, G. (1982). *The effects of speed limits on traffic accidents in Sweden*. In: *Proceedings of the international symposium on the effects of speed limits on traffic accidents and transport energy use*, 6-8 October 1981, Dublin. OECD, Paris, 1-8.
48. Nilsson, G. (2004). *Traffic safety dimensions and the power model to describe the effect of speed on safety*. Lund Bulletin 221. Lund Institute of Technology, Lund.
49. NNI (2006). *Functional use of colour - Accommodating colour vision disorders [Functioneel kleurgebruik - Aanpassing aan kleurzienstoornissen]* (Nederlandse praktijkrichtlijn, NPR 7022 (nl), april 2006, in Dutch). Delft, The Netherlands: Nederlands Normalisatie-instituut.
50. Petermeijer, S. M., De Winter, J. C., & Bengler, K. J. (2016). Vibrotactile displays: A survey with a view on highly automated driving. *IEEE Transactions on Intelligent Transportation Systems, 17*(4), 897–907.
51. Rijkswaterstaat Dienst Verkeer en Scheepvaart (2008). *10 Gouden regels om rekening te houden met de weggebruiker.* Delft, The Netherlands: Rijkswaterstaat

Dienst Verkeer en Scheepvaart. http://publicaties.minienm.nl/download-bijlage/19708/10-gouden-regels.pdf
52. Rijkswaterstaat Dienst Verkeer en Scheepvaart (2011). *Beoordeling van Objecten langs Auto(snel)wegen.* Delft, The Netherlands: Rijkswaterstaat Dienst Verkeer en Scheepvaart.
53. Rijkswaterstaat Dienst Verkeer en Scheepvaart (2012). *Gedrag weggebruikers. Een handreiking om beter grip te krijgen op gedrag.* Delft, The Netherlands: Rijkswaterstaat Dienst Verkeer en Scheepvaart.
54. Salusjärvi, M. (1990). In G. Nilsson (Ed.), *Speed and safety: research results from the Nordic countries*. Linköping: VTI.
55. Society of Automotive Engineers, 1993. *Design Criteria-driver Hand Controls Locations for Passenger Cars, Multi-Purpose Passenger Vehicles, and Trucks (10,000 GVW and Under).* SAE J1138, in 1993 SAE Handbook, Warrendale, PA: Author.
56. Srinivasan, R. & Jovaris, P.P. (1997). Effect of in-vehicle route guidance systems on driver workload and choice of vehicle speed: finding from a simulator experiment. In Noy, Y.I. (red.), *Ergonomics and Safety Intelligent Driver Interfaces*. Lawrence Erlbaum Associates, Mahwah, NJ.
57. Stevens, A., Quimby, A., Board, A., Kersloot, T. & Burns, P. (2002). *Design Guidelines for Safety of in-vehicle Information Systems.* Transport Research Laboratory, PA3721/01.
58. SWOV (2013). *SWOV-Fact Sheet. Distraction in traffic.* The Hague, Netherlands: SWOV Institute for Road Safety Research.
59. SWOV (2012). SWOV-*Fact Sheet. The relation between speed and crashes*. The Hague, Netherlands: SWOV Institute for Road Safety Research.
60. Transport Research Laboratory (2002). *Design guidelines for safety of in-vehicle information systems*. Wokingham, UK: TRL
61. Transport Research Laboratory (2011). *A checklist for the assessment of in-vehicle information systems (IVIS).* Wokingham: TRL.
62. Theeuwes, J., van der Horst, A.R.A. & Kuiken, M. (2012). *Designing safe road systems: A Human Factors perspective*. UK: Ashgate.
63. United States Department of Transportation (1989a). *Federal Motor Vehicle Safety Standard; Controls and Displays (Standard 101)*, Federal Register, March 9, 1987. Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration.
64. United States Department of Transportation (1989b). *Manual on Uniform Traffic Control Devices - 1988 edition (ANSI D6.1e - 1989)*. Washington, DC: Superintendent of Documents, U.S. Government Printing Office.
65. Werneke, J., Kleen, A., & Vollrath, M. (2014). Perfect timing: Urgency, not driving situations, influence the best timing to activate warnings. *Human factors*, *56*(2), 249-259.
66. Wickens, C.D. (1992). *Engineering psychology and human performance*. New York: HarperCollins.

67. Winkler, Werneke & Vollrath (2016). Timing of early warning stages in a multi stage collision warning system: Drivers' evaluation depending on situational influences. Transportation Research Part F, 36, 57-68. http://dx.doi.org/10.1016/j.trf.2015.11.001
68. Winkler, S., Kazazi, J. & Vollrath, M.(2018). How to warn drivers in various safety-critical situations – Different strategies, different reations. Accident Analysis and Prevention, 117, 410-426. https://doi.org/10.1016/j.aap.2018.01.040
69. Young, M.S., Brookhuis, K.A., Wickens, C.D., & Hancock, P.A. (2015). State of science: mental workload in ergonomics. *Ergonomics, 58*, 1-17.
70. Young, K., Regan, M., & Hammer, M. (2007). Driver distraction: A review of the literature. *Distracted driving*, 379-405.

5. Annex

Annex 1 The three-level model of the driving task (ref?)

Level	Explanation
Strategic	Finding the way through a road network (navigation) including, modifying modal choice, route choice and exposure (e.g. frequency and/or length of travel).
Manoeuvre (Tactic)	Changing lanes, keeping the vehicle on the lanes, including modifying speed choice.
Control (Operational)	Maintaining speed, headway and distance to other vehicles.