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D3.6 – ANNEX – Communication Guidelines

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1 Introduction

The user interface, system design and implementation of adaptation are essential parts of the adaptive-cooperative human-machine system. The human *operator needs to be informed about the system status*. Therefore, the machine agents have to provide *intuitive feedback* and visualization to increase the operator's understanding of the "*Why?*" and "*What?*" of the intended, anticipated or performed adaptation. For example, a machine agent within an Aeronautics AdCoS might communicate: "I display the fuel consumption for validation (the "*What?*") because we fly over a waypoint (the "*Why?*")".

When operating automated systems, partially due to their complexity, understanding the meaning of displayed information can represent a significant difficulty [1]. For instance, in aircraft systems, pilots have reported *significant difficulties* in understanding what their automated flight management systems are doing and why [2]. This problem can be directly linked to a lower level of situation awareness and conveys that AdCoS need to constantly communicate changes and adaptations to the human operators.

Due to the previous reasons, the focus of these guidelines will lie on the *communication strategies of the system adaptation*. As humans are limited by working memory and attention [3], it is crucial that AdCoS ensure perceptual salience of the most important information. To achieve this goal, the guidelines will analyze the different communication systems (visual, acoustic and tactile) for the "What" (adaptation that has occurred) and the "Why" (reason for the adaptation → context assessment).

To define a communication strategy, some main points should be addressed properly. The first of them will be the *objectives of the communication*. In the case of the different AdCoS, this will be the adaptation that occurred in the system and at has to be communicated to the operator.

On the second place, for our communication strategy to be widely effective, *the audience* to whom the communication is prepared for is fundamental. The operators and their specific state (Human Factors in context assessment) will be taken into account, provided that the perception of the communication could require extensive cognitive processing on the part of the user.

The next main issue in a communication strategy is the communication channel, understood as medium through which a message is transmitted to its intended audience. In our case, multimodal communication channels will be studied in order to define the best ones to achieve the communication objectives. In this sense three different channels will be taken into account:

1. visual (e.g. as pictures and characters),
2. acoustical (verbal or nonverbal) or
3. physical / tactile (e.g. vibration).

To finalize, strategies for evaluation and validation should be defined in order ensure the achievement of the communication objectives.

Summarizing, the Communication Guidelines will address the *following questions*:

- Which are the *different types of communication* with the operator?
- How should/can a communication strategy be implemented *(visual, acoustic, tactile)*?
- Why should *Human Factors* be considered when implementing a communication strategy?
- Are all communication strategies *valid* for every different domain / AdCoS?
- How can the different Human Factors *influence the perception* of the communication?
- How can a communication strategy be *tested*? / What variables need to be considered? (Verification of the system benefits)

2 Current situation in HoliDes AdCoS

The first step to determine the best way to communicate the adaptation changes to the operator is to analyze the current situation of the HMI in the different AdCoS. This analysis has been linked both with the context assessment (to determinate which Human Factors are involved in each AdCoS) and the adaptation produced in the system (the one that has to be communicated to the operator).

Extended information about the current situation in HoliDes AdCoS can be found in Appendix A.

3 Analysing the Communication Strategies

3.1 Communication objectives ("What?" and "Why?")

In the case of these guidelines and the specific chosen AdCoS, the communication objectives will be focused mainly in the appropriate communication and "explanation" of changes in the AdCoS (adaptation) to human agents. It is important in order to ensure safety – especially in the use cases which involve operating a vehicle. Beyond that, it is crucial for the development of an adequate degree of situation awareness and trust.
"What" is being communicated is widely dealt in *D3.6aPU*.

Furthermore, the second main communication objective is the "why", describing reasoning for adaptation actions. Recent studies [25] have shown the importance of providing information on the "why" to achieve, for example, a better driving experience in (semi-autonomous) adaptive vehicles. The explanation of the "why" also affects the operator's attitude and safety performance.

3.2 Subject: the operator and their Human Factors influencing perception ("Who?")

Human Perception

The main subject of the communication strategies is the own operator. Human operator perception requires sensory organs, the nervous system, and the brain to work together smoothly. Any breakdown in this system can prevent or change human perception of the world at large. The human brain is also limited in its ability to process information and takes certain shortcuts when processing the information that is received from the senses, especially during visual perception.

Perception is the process by which individuals organize and interpret the signals received through their sensory organs to give meaning to their environment. What we perceive is definitely influenced by the environment which generates the signal received by sensory organs. But the same signals are not perceived by all individuals in the same way. There are differences. As a matter of fact there may be difference in the way an individual perceives the same object in the environment under different conditions or context.

A simplified *model of human perception* has been presented by [30].
The model describes human visual perception as a three stages process:
1 – in the first step, the information is elaborated in parallel to extract basic features of the environment;
2 – in the second stage, processes of pattern perception extract structures and segment the visual scene into regions of different color, texture, and motion features;
3 – in the third step, the information is reduced in only a few objects held in visual working memory by attention processes.
Following this model, human perception is highly affected by individual *memory* and *attention* processes.

Memory organizes behaviour in time, making a link between past and future experiences [31]. Memory is not only the ability to reactivate, partially or totally, past events, but also the ability to generate new interpretative schemes of reality and to plan acts deferred in time [32].
In many years of research, different models of memory have been built.
Associative models of memory based on elementary mechanisms reduced the human being to a passive receptor of stimuli. To overcome this limit, further studies have allowed the development of more complex memory models - *cognitive models*. One of the most popular was made by Atkinson e Shriffin ([33],[34]). This model is based on a concept of human being like data elaborator.

The first step of the elaboration of local stimuli takes place at sensory registers level. In *sensory memory*, information is detained very little time: 250 milliseconds visual information in iconic memory and 200 milliseconds auditory information in echoic memory.

In the next step, short term memory doesn't contain only sensory images of external stimuli but make an interpretation.

Finally, *long term memory* can retain information for a long time. Memory shift between these two levels is possible through a mechanism of track repetition. Quality and quantity of repetition causes the memory traces strength.

Distinction between short-term memory and long-term memory is supported by behavioural and neurological data. As memory is not a unitary store, we can distinguish between different memory systems: *working memory, episodic, semantic* and *procedural* or *implicit memory*.

Initially, researchers attributed to *short term memory* very elementary processes like the rehearsal. Sperling [35] described this process like an internal voice with a purpose to revitalize information to prevent the loss.

Recent theories, however, suggested that short-term memory presupposes mechanisms more complex than rehearsal. Current idea of short term memory is that of a limited capacity system which temporarily holds active information and supports thought processes by connecting perception, long term memory and action. This system is also known as *working memory* [36].

As already discussed in D2.1, the first author who replaced the concept of short-term memory with that of working memory was Baddeley [37]. According to this author, working memory is a system whose role is to detain and manipulate information during cognitive tasks execution, like comprehension, learning and thinking [38].
This system is constituted by:

- the phonological loop: it is the component better illustrated by Baddley. It includes two sub-components: a phonological store whose work is to hold linguistic information and an articulatory rehearsal process based on an internal speech. After very little time, about two seconds, information contained in the phonological store declines but it is possible to keep active memory trace with a process of sub-vocal rehearsal. This theory is supported by experimental data:
    - the phonological similarity effect: a high robust effect consisting in impaired immediate serial recall of elements phonologically similar;
    - the word length effect: difficulties in long words due to the fact that long words contain more elements and are more fragile;
    - irrelevant sounds effect: impaired recall due to the contemporary presentation of critical elements and irrelevant material. Irrelevant material presentation interferes with phonological loop work and it doesn't allow sub-vocal rehearsal. Phonological loop seems to be

very important in different processes like learning to read or written words comprehension.

- the visuospatial sketchpad: it elaborates visual and spatial information. It works like its verbal equivalent, the phonological loop, elaborating four or five objects at a time;
- the central executive: it is a control system, similar to an attentive mechanism involved in decision making processes.

With regard to *long term memory*, Tulving in 1972 undermined unitary theories of long term memory suggesting a distinction between *semantic* and *episodic* memory based on the encoding specificity principle [39]. Tulving implemented an experiment where subjects were asked to memorize twenty-four pairs of words, constituted by a target word and a weak cue for recall; afterwards a list of words closely related to the targets words were presented to the subjects asking them to create free connections between materials. The result of this experiment evidenced that, in presence of semantically related words, participants were able to recall the targets but not to identify them like critical words. So semantic information didn't allow reaching information stored in episodic memory. According to the author, episodic memory is auto-noetic because it concerns personal experiences. Semantic memory, on the contrary, is noetic because we are aware of elements not available from immediate circumstances. Tulving imaged semantic memory like a mental dictionary, which contains words, concepts and links between the two.
In addition, Tulving [40] assumed the existence of a third type of long term memory system, *procedural memory*, that refer to skills and rules acquisition, to a tacit "know how" which is essential in tasks that required cleverness, like to use a bike, to drive a car and so on. Schacter [41] prefer to call this form of memory *implicit memory*, emphasizing the fact that information about events is reactivated without awareness.

As stated before, together with memory the other factors to be taken into account when dealing with perception processes, is attention.
A theory that strongly relates perception and attention is the feature integration theory proposed by Treisman [42]. According to the author attention processes are based on a fundamental process of feature extraction, a process operating outside of consciousness that is responsible for objects detection in terms of extraction of features like shape, colour, depth, movement.

Factors affecting human perception

In the case of the HoliDes project, the AdCoS should communicate changes to human agents to keep the human agent actively involved in the decision making loop. However, if the provision of such feedback requires *extensive cognitive processing* on the part of the user, any benefit may be counteracted by increased cognitive load. Consequently, there is a need to develop interfaces that provide feedback on automation states and behaviors in a manner that requires *little or no cognitive effort* but can be directly apprehended by a quick glance at a display that provides the appropriate avenue for rapid action.

The aim of this section is to analyze the different states in which the operator can be and also the way these Human Factors *can affect to the perception* of the information.

Till the moment, the different Human Factors that are being considered in the different chosen AdCoS are:

- Fatigue
- Distraction
- Workload
- Situational awareness

You can find examples on how the Human Factors can affect the perception of communication on Appendix B.

When dealing with situational awareness (SA), long-term memory, working memory and attention mechanisms are relevant. The concept of SA has been introduced for the first time in the late 80s in the fighter aircraft domain. The use of the concept has rapidly spread in other domains, from driving to medicine, prompted by the technological development that has required operators to deal with a lot of information coming from different sources. The emphasis on SA has been motivated by the effort of designers to project and realize decision aids and system interfaces to accomplish operators needs in managing the huge quantity of information. Informally speaking, Endsley [43] defines SA in terms of "knowing what is going on" in a specific environment. A more formal definition describes SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". SA is the base for decision making, as the way a problem is framed influences the decision to solve it. SA, even if not directly, also influences the performance: a poor performance is supposed to be a consequence of an incorrect of incomplete SA. However, an operator conscious of the lack of SA can modify the behaviour to reduce the possibility of poor performance [44].

Distraction can be defined as a state in which attention is captured by information not relevant for a primary task in a way that corrupts the performance in the primary task. Distraction effects in safety critical domains have been studied mainly in automotive. Distraction can be mainly distinguished in visual and cognitive, defined by [45] respectively "eye off-road" and "mind off-road". Cognitive distraction is related to a mental distraction, for example, concentrating on a conversation. Visual distraction can come for example from looking at a telephone keypad in order to dial, or reading or composing a text message. Research has shown that both type of distractions impairs drivers' vehicle control (especially lane position and maintenance of appropriate speed) and reduces drivers' situation awareness, resulting in slower reaction times and less use of mirrors [49].

Mental fatigue can be defined as a change in the psycho-physiological state due to a prolonged performance. That prolonged performance not necessarily relies on a single task but can also include more tasks all involving a mental effort. Changes in the psycho-physiological state cause subjective and objective effects, as mood changes or an increasing resistance to further efforts. One of the most compelling hypothesis reported in literature links fatigue effects to an impaired executive control [46]. The executive control is conceived as a limited resource for controlled processing especially for activities such as planning, problem solving, and task scheduling. An hypothesis is that the prolonged (over)use of this mechanism is the cause for the phenomena of mental fatigue [47].

Finally, the cognitive workload can be defined as a condition that can be revealed by poor performance measures in a task due to a secondary interfering task [48]. The cognitive workload has been studied experimentally by means of the dual task paradigm in which the performances of participants are measured in terms of response times in the execution of both the primary and the secondary task. An explanation of workload effects is attributed to the limited capacity of working memory [37]. It is accepted that there is a relationship between the media by which information is transferred and presented to a decision maker and their cognitive workload. During periods of concentrated activity the balance between the different information channels (e.g., visual processing and auditory) has a positive impact on cognitive workload [51]. In a time-constrained application context, the cognitive workload can lead to human error or delayed decisions to accommodate the processing of the relevant information [52].

Human Factor	***Description***	***Influence in the information perception***
Fatigue	A state due to a prolonged mental effort	A high level of fatigue causes subjective and objective effects, as mood changes or an increasing resistance to further efforts. One of the most compelling hypothesis reported in literature links fatigue effects to an impaired executive control.
Distraction	A state in which attention is captured by information not relevant for the primary task in a way that corrupts the performance in the primary task	Visual distraction can lead to the loss of important information, that are then not to be perceived at all. Cognitive distraction can worsen the processing of the perceived information in terms of time.
Workload	A state that can be revealed by a worsening of the performance measures in the primary task due to the presence of secondary interfering tasks	Delayed information processing affecting decision making
Situational awareness	The perception and comprehension of the elements in the environment and the projection of their status in the near future	A high level of situational awareness has positive impact on the successfulness of decision making processes, thanks to a better comprehension of the perceived contextual information.

3.3 Channels: multimodal communication strategies ("How?")

Multimodal communication systems process two or more combined user input modes in a coordinated manner with multimedia system output.

Of the numerous ways explored by researchers to enhance human-computer communication, multimodal interaction has shown much development in the past decade. The advantages of this multimodal interfaces are twofold:

- Users are offered a more "human" way of interacting with computers, because they are provided with alternative modes of input / output other than the usual human-computer interaction as unimodal interface [13].
- Offer a better flexibility and reliability and make the system more robust than other human-machine interaction means [14] (reducing error in the communication).

As described in [15], the generic components for handling multimodal communication in a system are mainly a fusion engine (for the combination of input modalities) and a fission module (to divide information through active outputs). In these guidelines, we are focusing in the fission process. Here we have an example of multimodal system and its generic components:

An important issue for communication processes in general, and for multimodal interaction in particular, is the information output arrangement and organization (***multimodal fission***). Considering information structure, intonation and emphasis for the output by speech, considering moreover spatio-temporal coordination of pieces of information for visual (video, graphics, images and text) outputs, designing output for each kind of modality, and synchronizing the different outputs modalities is one of the most relevant challenges of the multimodal interaction design process, it is called ***fission***.

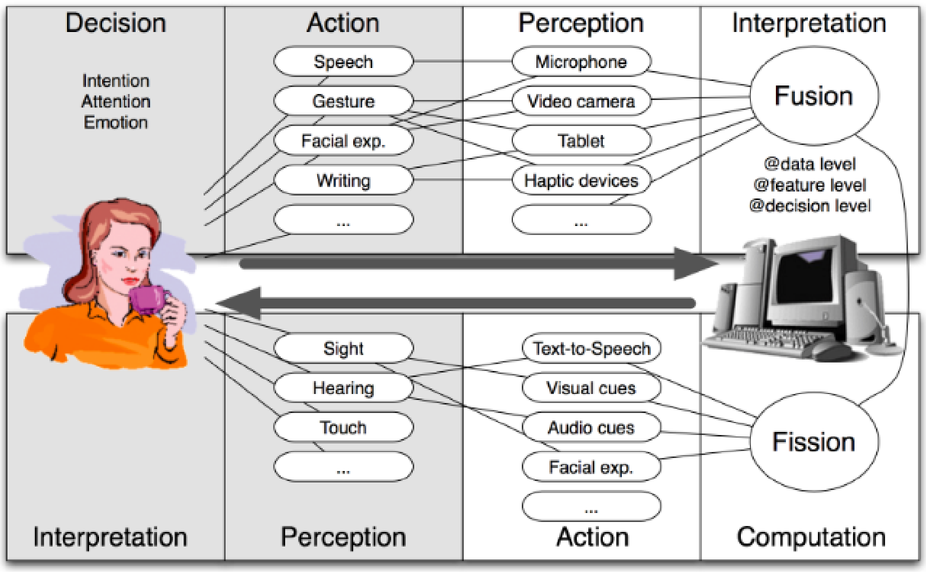

Figure 1: Multimodal fission architecture

Concretely in HoliDes project, for the action and communication in the AdCoS it is necessary to take into account the Human Machine Interaction, from the point of view of the fission module (the output of the system for the human).

This section is mainly focused in the information the machines can give about their adaptation to the operator, that's to say the fission process (multimodal output). From their side, machines can give information mainly in three ways:

- visually (e.g. as pictures and characters),
- acoustically (verbal or nonverbal) or
- physically/tactile (e.g. vibration).

In conclusion, the AdCoS should provide information via different output modalities, exploiting the various different *sensory channels available* to humans by providing tactile, auditory, and peripheral visual feedback.

3.3.1 Visual communication strategies: Interface Design

There is a need for communicating the adaptation in a visual way to the operator. Like with any language the machine needs to understand the individual parts, how to organize those parts and re-arrange them in order to transmit the message.

One explicit goal of visualization is to present data to human observers in a way that is informative and meaningful, on the one hand, yet intuitive and effortless on the other.

Visualization in general has the potential to closely interact with users and adapt to their needs, e.g. *mental models, cognitive processes and affective states*, in order to improve performance and increase user satisfaction. These visualization systems should be aware of user emotions and needs, in this way increasing the adaptability of the representation and the overall impact of visualization effectiveness.

The beginning for visualization strategies definition is to try to get advantage of some of the built-in capabilities and also to take into account the limitations of the human visual system.

In this sense of human capabilities, preattentive vision refers to cognitive operations that can be performed prior to focusing attention on any particular region of an image. In [4], the authors argue that results from research on this ability could be used to assist in the design of visualization tools.

As a limitation of visual human capabilities, we can find the term of "Change blindness". It refers to the finding that large changes to the visual world go undetected if attention is not already focused on the objects or area in which the change occurs [5][6][7].

Preattentive proccesing

Preattentive processing is defined as the ability of the low-level human visual system to rapidly identify certain basic visual properties.

For many years vision researchers have been investigating how the human visual system analyses images. An important initial result was the discovery of a limited set of visual properties that are detected very rapidly and accurately by the low level visual system. These properties were initially called *preattentive,* since their detection seemed to precede focused attention.

We now know that attention plays a critical role in what we see, even at this early stage of vision. The term preattentive continues to be used, however, since it conveys an intuitive notion of the speed and ease with which these properties are identified.

Typically, tasks that can be performed on large multi-element displays in less than 200 to 250 milliseconds (msec.) are considered preattentive. Eye movements take at least 200 msec. to initiate, and random locations of the elements in the display ensure that attention cannot be pre-focused on any particular location, yet viewers report that these tasks can be completed with very little effort. This suggests that certain information in the display is processed in parallel by the low level visual system.

As a summary, preattentive processing asks in part: "What visual properties draw our eyes, and therefore our focus of attention to a particular object in scene?"

Preattentive perception is done in parallel, but attentive processing is done serially and is, therefore, much slower [16]. Here is an example to illustrate the difference between these two types of visual perception.

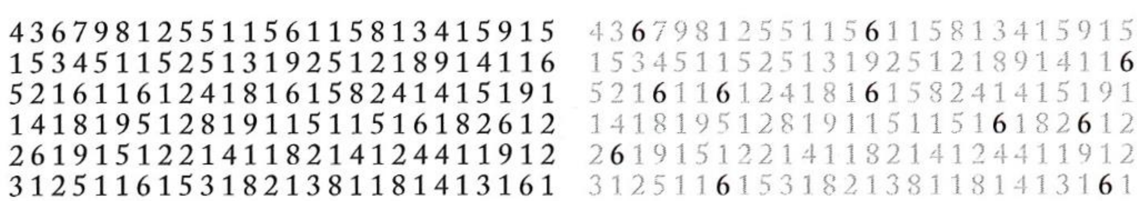

Figure 2: It is easier to spot the number 6 on the right image (preattentive processing) than on the image on the left (attentive processing)

This example demonstrates that the brain is much better at quickly detecting shade variations than shape differences [17].

Change Blindness

New research in psychophysics has shown that an interruption in what is being seen (*e.g.,* a blink, an eye saccade, or a blank screen) renders us "blind" to significant changes that occur in the scene during the interruption. This *change blindness* phenomena can be illustrated using a task similar to a game that has amused children reading the comic strips for many years [5], [8], [9].

A second hypothesis is that only the initial view of a scene is abstracted. This is plausible, since the purpose of perception is to rapidly understand our surroundings. Once this is done, if the scene is not perceived to have changed, features of the scene should not need to be reencoded.
This means that change will not be detected except for objects in the focus of attention. One example of this phenomenon is an experiment conducted by Levins and Simon [10], [11].

3.3.2 Acoustic communication strategies

Acoustic signals are omni directional (i.e. they travel in all directions) and can be broadcast to a large audience including intended and unintended listeners, and those in view and hidden from view. Being short-lived and deliberate, acoustic signals are useful for giving information about an *immediate situation*, rather than about a constant state (as it can happen for example in an alert or emergency situation).

The auditory modality is highly effective at conveying instructions and other relevant information via speech [18]. Verbal instructions (rather than visual text) are particularly effective when a listener is performing a task or in motion.

Auditory cues are also well-suited for rapid cuing of critical information, such as for warning and alarms [19]. When reaction time is essential, auditory warnings are generally superior to visual warnings, as they more efficiently draw attention to critical information (30 to 40 ms faster than vision)[20], see also [21]. In fact, the acute temporal resolution of the auditory system is one of its greatest assets [22].

When it comes to the specific auditory cue to use, tones are good for communicating limited information sources; complex sounds are well-suited to alarms; speech is more effective for rapid communication of complex, multidimensional information sources [23], and timbre (ie sound quality) is an effective auditory grouping cue [24].

3.3.3 Tactile communication strategies

The sense of feel *is not typically used* as a man-machine communication channel, however it is every bit as acute as the senses of sight and sound. Using an intuitive body-referenced organization of vibro-tactile stimuli, information can be "displayed" to a person. Tactile displays can reduce perceived workload by its easy-to-interpret, intuitive nature, and can convey information without diverting the user's attention away from the operational task at hand.

The key to successful implementation of tactile displays lies in the ability to convey a strong vibro-tactile sensation to the body with compact, lightweight devices that can be *comfortably incorporated* in the user's workspace, or clothing, without impairing movement. These devices must be safe and reliable in harsh environments, and drive circuitry should be compatible with standard digital communication protocols.

Tactile cues, such as those conveyed via vibrations or varying pressures, can provide information concerning location, texture, softness and surface viscosity, as well as serve as effective simple alerts ([27] and [25]). The vibrotactile sense is comparable in discriminatory ability to audition for frequencies up to about 50 Hz, after which point audition is far superior [26].

3.3.4 Other sensory communication strategies

Although the technology is not quite operational, it is informative to consider the design benefits that may be derived by incorporating additional communication modalities, such as olfaction, gustation, vestibular stimulation, pain and temperature.

Olfaction, which is best conveyed via different odors rather than variations of a given odor. Holds particular promise as it can be used to manipulate mood, decrease stress, increases vigilance and aid memory ([27] and [25]). Humans can detect approximately 10.000 different odors; however, if only intensity is varied, one can detect only about three or four different smells at a time [28].

Olfatory cues are generally most appropriate for conveying affective or ambient information, as well as slow-moving, medium duration information, as odors linger and their persistence varies. Due to the nature in which the olfactory receptors are distributed, olfactory cues are not appropriate for conveying spatial information [29].

3.4 Evaluation and validation strategies

In order to set up the evaluation of the multichannel communication strategies, some elements should be taken into account.

For example in the case of the automotive domain, the interface should communicate to the driver "what" to do (e.g. turn right; turn left; keep the lane) in a visual or visual and verbal manner according to the context, which means being in presence of obstacles, being distracted, having a specific intention and so on. Several studies have shown that the drivers tend to trust more in semi-automatic systems if the devices communicate in an efficient manner and explain the "why" of certain actions and decisions suggested (e.g. keep the lane and avoid overtaking because a car is approaching). However, it is difficult to transfer these messages verbally.

One possibility consists in using other perceptual channels that in a given moment result free from processing, as for example the haptic channels (vibration of the seat or of the steering wheel). While the use of an alternative channel can be considered reasonable and easy to understand on an intuitive ground, the effectiveness of the different available alternative channels needs to be verified on a scientific basis. Empirical analysis is a possible applicable methodology to this aim.

In order to evaluate and compare the effects of the different strategies for the communication of the "why" of the adaptation, a series of experiments will be created.

In the first series of experiments acoustic, visual and haptic stimuli will be compared in the driving simulator to evaluate which one interfere less with the driving activity.

Once established the channels that better adapt to a specific task, a series of experiments using intra/intermodal paradigms will be set up to verify which specific features of, for example, an acoustic channel, are better processed by the driver or on which frequency the vibration of the seat/the wheel can alert the driver of an imminent danger.

Finally, participants will be interviewed to collect information useful to eventually modify the interface. Combined the results will provide evidence on the evaluation of the interface.

4 Guidelines for communication

The following section will give the full list of these Human Factors guidelines for communication the adaptation.

For the moment, the guidelines are mainly focused on the visual communication. Next versions of this document will broad the scope of the guidelines.

GUIDELINE #1
Name of guideline
Visual design should have into account the preattentive attributes of perception
Description
Preattentive processing, the early stage of visual perception that rapidly occurs below the level of consciousness, is tuned to detect a specific set of visual attributes. These visual attributes aren't perceptually equal. Some are perceptually stronger than others. Some can be perceived quantitatively and can therefore be used to encode numeric values, and others can't.
Examples
A complete description of the preattentive principles and some explanatory examples can be found at Appendix C, section 1
Sources
Information Dashboard Design, Stephen Few [55] Perception for Design, Colin Ware [30] The Functional Art, Alberto Cairo [56] Tapping the Power of Visual Perception, Stephen Few [57] Principles of Data Visualization – What we see in a visual (White Paper from FusionCharts) [58]

GUIDELINE #2
Name of guideline
Visual design should have into account the Gelstat Principles to bring out patterns in visualization
Description

Gestalt principles describe how our mind organizes individual elements into groups. We can use these principles to highlight patterns that are important, and downplay other patterns.
Examples
A complete description of the Gelstat principles and some explanatory examples can be found at Appendix C, section 2
Sources
Information Dashboard Design, Stephen Few [55] The functional Art, Alberto Cairo [56] Principles of Data Visualization – What we see in a visual (White Paper from FusionCharts) [58]

GUIDELINE #3
Name of guideline
Display the data as clearly and simply as possible, and avoid unnecessary and distracting decoration.
Description
This guideline is directly related to maximize the data-ink ratio, within reason. Every bit of ink on a graphic requires a reason. And nearly that reason should be that the ink presents new information.
Examples
A complete description of the data-ink ratio and some explanatory examples can be found at Appendix C, section 3
Sources
Information Dashboard Design, Stephen Few [55] The functional Art, Alberto Cairo [56] The Visual Display of Quantitative Information, Edward R. Tufte [59]

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Appendix A

1 UC1 Guided Patient Positioning

1.1 Current situation analysis

UC1 is the Health use case, Guided patient positioning.

In the Guided patient positioning use case, assistance is provided to an operator aiming at safely positioning a patient in an MRI device for medical examination purposes.

CASE 1	
Human Factor	***Process***
Non-standard activity (measures by scanner signals and respiratory sensor for the patient breathing)	Assessment of operator's compliance with standard procedure and guidance in case of deviations
Adaptation	
On-line guidance and information about current system configuration during preparation of the patient for the MRI scanning procedure. The system includes transparent adaptive algorithms, mostly based on fall-back procedures. This for instance means that if a specific coil (say, a knee coil) has not been mounted, the system will allow continuing with the scan using the built-in generic coil. This system adapts by modifying the positioning procedure and the UI that presents that procedure.	
Communication	
The change in the UI is the visible manifestation of the adaptation. Adaptation in the UI of the guidance system is obtained by modifying the graphical representation of the positioning steps according to the requirements of the examination as obtained from the overall context information. The display will be re-configured automatically to show the relevant steps of the positioning procedure, which includes information to give to the patient.	
Type of Interaction	
Visual, one-way	
AdCoS / MTT responsible	
Gantry display (guidance display)	

1.2 AdCoS communication description

The Guided patient positioning system provides guidance to operators of MRI scanner during preparing and positioning patients for MRI examinations. Correct positioning of the patient for the MRI examination and using the right coils and other devices are important to get good diagnostic quality images, but also important to avoid safety issues. Currently, operators are trained for this. The on-line guidance system intends to improve usability and to reduce risks, also in case of novice, less experienced users.

The communication of the adaptation in the system is achieved through the guidance display. The display will be re-configured automatically to show the relevant steps of the positioning procedure, which includes information to give to the patient.

Figure 3 shows an example of a display that has been re-configured to communicate the structure of the guidance procedure based on the context information.

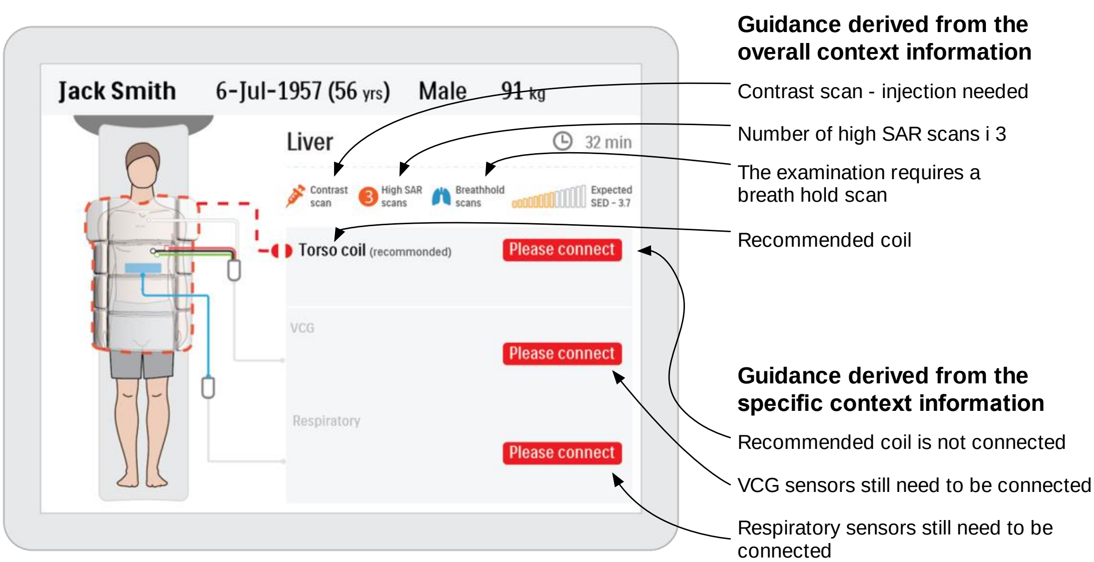

Figure 3: A display showing the guidance given to the operator

From the overall context information, the necessary steps of the procedure are shown:

- An injection is needed as the examination includes a contrast scan.

- The number of high SAR (Specific Absorption Rate, the RF energy deposited in the tissue) scans is three, so for three scans in the examination the patient may experience additional heating. The operator can use this to inform the patient.
- The examination requires a breath hold scan, for which special instructions to the patient are needed.

From the specific context information, the progress of the positioning is monitored, and the advice on next steps is given – in this case to connect the coil and VCG (for the heart-rate detection) and respiratory sensors.
In a later stage, if the required devices are connected, the display will provide information on the status of the connection. In case of coils it will show if the coils are properly connected. For physiology signals (VCG and respiratory) the display will directly show the heart-rate and respiratory graphs, including an indication of the quality.
If the quality is low, additional guidance may be provided to the operator on the display.

2 UC2 Diversion Airport

2.1 Current situation analysis

In UC2, Diversion Airport, assistance is provided to the pilot through the DivA (DIVersion Assistant) system. DivA helps the pilot by providing tentative diversion flight plans (F-PLN) when a diversion is needed.
Analyzing the different Human Factors related with the adaptation and the communication to the pilot, the following information is available:

CASE 1	
Human Factor	***Process***
Fatigue	Pilot’s state assessment
Adaptation	
Methods for operator state inference being evaluated (physiological metrics, camera monitoring, voice detection)	
Communication	
Info reduction – pre-selection of options, change in calculation strategy, visual prioritization	
Type of Interaction	
Visual	
AdCoS / MTT responsible	

External pilot models and pattern classifier

CASE 2	
Human Factor	***Process***
Distraction	Missed event detector (MED)
Adaptation	
Methods for operator state inference being evaluated (physiological metrics, camera monitoring, voice detection)	
Communication	
1. Test case - auditory warning about the event 2. AdCoS - holding the event from disappearing until observed	
Type of Interaction	
Visual	
AdCoS / MTT responsible	
MED (Missed Event Detector) and Diversion Assistant	

Summarizing, the pilot gathers information on the F-PLN through user interfaces (UI) resources: the Navigation Display/Vertical Display (ND/VD) UI and the Flight Management System (FMS) UI. The pilot acts on the F-PLN through the FMS UI. The pilot also *receives assistance* from the DivA system through the *DivA UI*. That assistance is provided at the level of the Action Planning (AP) cognitive step: The pilot has to plan a new diversion plan and there are several options ordered by computed relevance in DivA UI.
For the moment, in this Use Case there are only basic ideas on adaptation, which will be implemented in future milestones. So the communication of adaptation is not being done at this step.

2.2 AdCos Communication Description

Diversion assistant (DivA) is an application that will assist the pilot in the integration and evaluation of various types of information in situations when original destination and alternates become unavailable due to airport closure and/or weather restrictions. In such situations, pilots need to consider various sources of information – for aircraft performance, overall weather situation, parameters for airports in reach etc. Based on the updated

information, pilots are supposed to evaluate options for available airports and negotiate approach and landing for the selected one.
DivA will take into account cockpit conditions, workload, or fatigue of the pilot, i.e. the calculations and HMI will be adapted to actual situation.
The development process of DivA HMI prototype has started from interview of HON pilots. Based on that, the functions and scope of the system were defined (coarse analysis, detailed analysis selected candidate airport among others), together with several HMI and workflow alternatives. HON and external pilots reviewed the concepts and selected the final design.
From the first series of user interviews, the graphical elements with required features were selected (airport option list, geographical area selection circle, brief airport information and detailed airport information).
In another series of interview with the pilots, the final design concept was decided.
The workflow of diversion assistant AdCoS (DivA) will be the following:

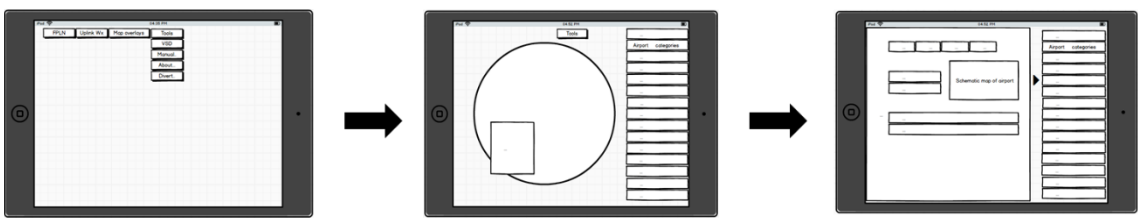

Figure 4: Selected communication workflow of diversion assistant

In this communication workflow, two modes are supported:

- Fast debrief that brings a default solution at the least amount of time. This solution shows overall status and pilots use it in time pressure to reduce his workload (second screen).
- A configurable interface allowing pilots to exploit the information of their situation (by use of floating window or a summary list with extending info-table) (third screen).

3 UC3 Command and Control Room

3.1 Current situation analysis

UC3 is the Command and Control Room use case, concerned in particular with the Headquarter Control Room sector, and within it, the Surveillance capabilities (at the moment the Response capabilities are not concerned by the AdCoS).

In UC3, assistance is provided to the surveillance operators/supervisors through the Adaptation Assistant Modules (AAM). AAM help the operators/supervisors by providing support in task execution or task allocation when border surveillance efficiency is needed.

CASE 1	
Human Factor	***Process***
Workload	Task workload distribution assessment
Adaptation	
Rebalance workload among all available operators / re-assignment can be performed either with or without involvement of the supervisor. Workload balancing is achieved by the AAM.	
Communication	
Once a load balancing decision has been made it is communicated to the operators involved, in terms of task assignment. This can be done verbally, directly by the supervisor and/or through an electronic messaging system (e.g. mobile phones, kinesthetic bracelet). These operators are then monitored to ensure their actions correctly follow the new instructions.	
Type of Interaction	
Verbal / Visual / Tactile	
AdCoS / MTT responsible	
workstation	

In term of **communication**, WP3 contributes to the following UC:

UC3.1 Operator Absent from Work Place: If operators are absent for longer than the permitted time, the systems calls them back to their workstations by means of discrete actuators worn by the operators.

UC3.2 Operator Idle at Work Place: If operators display a lack of movement for a longer period of time, the system wakes them by same means as UC3.1.

UC3.3 Operator Tired at Work Place*:* If the operator displays symptoms of fatigue, the system suggests to the operator to take appropriate measures.

UC3.4 Load Balancing on Operator Level*:* The re-assigning of individual events will be supported by appropriate information of the operator and his supervisor.

3.2 AdCos Communication Description

The Airbus DS demonstration will be the Command and Control Room use case, concerned in particular with the Headquarter Control Room sector, and within it, the Surveillance capabilities.

The following description of the command and control room communications will focus on the Workload Balancing use case. Figure 5 shows all communications that enable a functional allocation of tasks between operators.

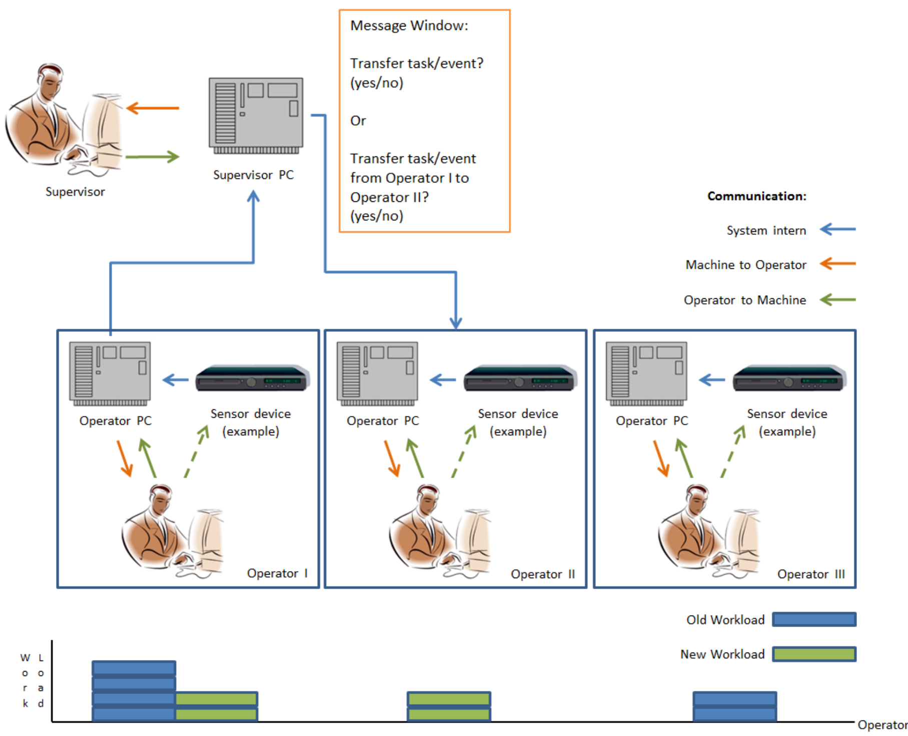

Figure 5: Communications in UC3 and workload-transfer-diagram

The communications in the specific use case can be categorized into system internal, machine to operator, and operator to machine communications. A sensor device and the operator PC collect data about the objective and subjective workload of the operator measured by direct (via hardware like keyboard) and indirect (via sensor device) inputs. The information is processed and sent to the supervisor PC. The PC generates a message window that informs the supervisor in one of two ways (depending on the selected scenario). One message indicates the affected operator and leaves the decision of which person to transfer the tasks to the supervisor. The other possible message indicates that workload needs to be shifted from an operator to a preselected operator with currently low workload. In the first case the supervisor needs to select a new operator to shift a task to and to confirm his/her decision. In the second case the supervisor only needs to accept or reject the allocation of tasks. If the supervisor confirms the movement of a task both operators receive a message window informing them that a task was taken from them or that a new task had been transferred to them. In both cases the operator needs to confirm that he read and understood the information. The operator does not have the chance to reject a request.

When considering Human Factors the communications between machine-operator and operator-machine are most relevant. For evaluating the current state of the operator system internal communications between sensors and computers are of interest. To achieve a complete picture of all communicators in the selected use case, Table 1 and Table 2 give detailed information.

Machine (Sensor) to Machine (Computer) Communication	
Parameters evaluated by sensor or operator pc	**Category of criteria triggering notifications to supervisor** (Categories by [60])
Number of critical events (task load)	Critical event
Level of fatigue	Psychophysiology
Level of experience	Operator performance
Keyboard/mouse activity, input frequency, Respond time, accuracy of response	Model-based
Time to solve incidents	Model-based (workflow-time-schedule)

Number of errors	Operator performance

Table 1: System intern communications

Operator → Machine		
Type of communication	**Execution**	**System requirements**
Haptic/motoric	press button, move and press mouse	Buttons (Keyboard, Mouse, Touch Pad etc.)
Machine → Operator/Supervisor		
Visual	Message window	Screen/Display

Table 2: HMI communications

Requirements/risks for the communication-design in the use case
Criteria need to be well designed to generate reliable messages in an appropriate manner (e.g. pop-up rate).
Each notification will distract the operator/supervisor in his current workflow. Therefore the operator/supervisor should only be interrupted when the workload is low or one task is finished. Other rules should be applied for safety critical tasks.
Information need to be clear with respect to the questions which task is transferred and who is in charge. Otherwise errors could occur due to forgetting tasks because the operator is not aware of the tasks currently assigned to him/her (situation awareness).

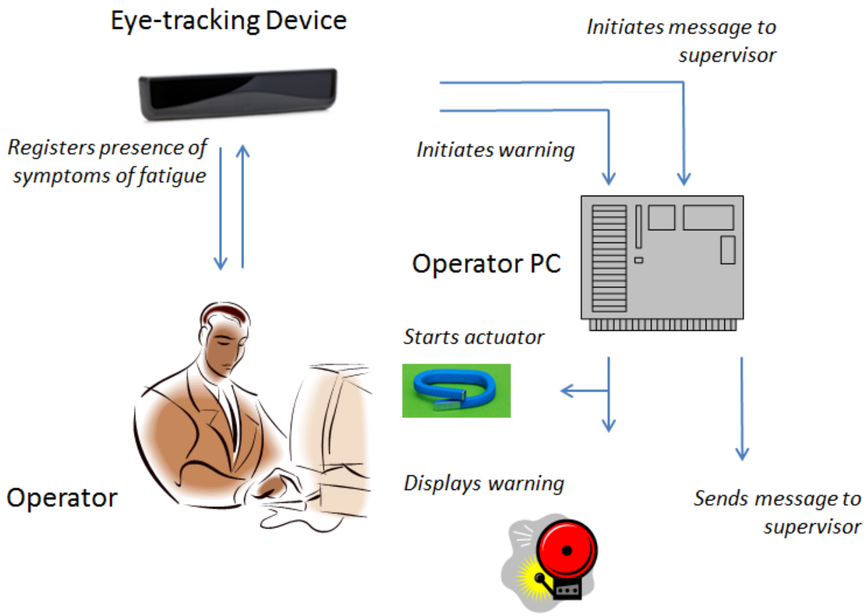

Figure 6: High Level Interaction Diagram for Control Room UC 3

4 UC4 Overtaking including lane change assistant

4.1 Current situation analysis

UC4 is the automotive use case, Overtaking including lane change assistant.
In UC4, Overtaking including lane change assistant, assistance is provided to the driver through the co-pilot concept, which can be regarded as composed of three functionalities: FCW (Forward Collision Warning), OTA (Over Taking Assistant), and LCA (Lane Change Assistant).

CASE 1	
Human Factor	***Process***
Distraction	Driver's visual distraction Driver's distraction level assessment
Adaptation	

Lane Change Assistant (LCA) will provide a level of support, depending on the driver's state, from a simple warning to the possibility to inhibit the maneuver
Communication
Information delivery Warning Actions on vehicle commands Automated driving
Type of Interaction
Visual / Acoustic / Haptic, depending on the level of distraction and the behavioral intention
AdCoS / MTT responsible
ADAS UI (joint user interface for FCW, OTA and LCA)

CASE 2	
Human Factor	***Process***
Behavioral intention	Driver's intention recognition
Adaptation	
Lane Change Assistant (LCA) will provide a level of support, depending on the driver's state, from a simple warning to the possibility to inhibit the maneuver	
Communication	
Information delivery Warning Actions on vehicle commands Automated driving	
Type of Interaction	
Visual / Acoustic / Haptic, depending on the level of distraction and the behavioural intention	
AdCoS / MTT responsible	
ADAS UI (joint user interface for FCW, OTA and LCA)	

4.2 AdCoS Communication Description

In Task 3.5 REL is expected to implement techniques and tools for the multi-modal (visual, acoustic, haptic and tactile) interface and communication between Humans and Machines addressing the HMI models developed in WP2.
The precondition for the definition of these interfaces and communication strategies was the creation of a model of a concrete AdCoS developed in WP6-9.
The AdCoS selected for the modelling was the Overtaking Assistant developed in WP9, and in particular its HMI.

As already described in *Deliverables D9.3* and *D2.4*, preliminary task modelling and task analysis have been carried out by REL on the Overtaking (OT) Maneuver.
The task modelling provides a general description of the tasks involved with making a Overtaking (OT) Maneuver. These tasks are preliminary cognitive, motor, visual or some combination thereof.
According to the cognitive, motor and visual tasks that the driver must complete in each phase, he/she has different cognitive, motor and visual loads, summarized in Table 3.

Task		Decision	Preparation	Execution
1. Changing the original lane	**Cognitive load**	medium	medium	medium
	Visual load	high	high	medium
2. Vehicle passing	**Cognitive load**	low	low	low
	Visual load	medium	low	medium
3. Re-entering into the	**Cognitive load**	medium	medium	medium
	Visual load	high	high	medium

Table 3: Cognitive, motor and visual loads in each subtask

Table 3 provides a relevant support for the design of the HMI of the AdCoS. In fact, the HMI of the AdCoS (OT assistant) can adapt to the status of the driver (distraction, intention, etc.) and the status of the environment (other cars approaching) and provides different information to the driver with different interaction modalities (visual, haptic and acoustic) **according to the expected cognitive and visual load in each task.**

The preliminary HMI concept (shown in Table 4) has been based on the information included in Table 3.

Task		**Decision**	**Preparation**	**Execution**
1. Changing the original lane	**Cognitive load**	medium	medium	medium
	Visual load	high	high	medium
	Information based on driver intention?	Information provided **only** if intention of changing lane was detected (driver intention module OR left indicator activated)	Information provided **only** if intention of changing lane was detected (driver intention module OR left indicator activated)	Information based on detection of LC manoeuvre
	Interaction modality	**Option 1.1** (driver not distracted AND no car approaching on the left): **visual** **Option 1.2** (driver distracted OR cars approaching on the left): **visual + acoustic**	**Option 1.1** (driver not distracted AND no car approaching on the left): **visual** **Option 1.2** (driver distracted OR cars approaching on the left): **visual + acoustic**	**Option 1.1** (driver not distracted AND no car approaching on the left): **visual** **Option 1.2** (driver distracted OR cars approaching on the left): **visual + acoustic**
2. Vehicle Passing	**Cognitive load**	low	low	low
	Visual load	medium	low	medium
	Information based on driver intention?	Information provided **only** if intention of changing lane was **NOT** detected (driver intention module OR right indicator **NOT** activated)	Information provided **only** if intention of changing lane was **NOT** detected (driver intention module OR right indicator activated)	Information provided **only** if intention of changing lane was **NOT** detected (driver intention module OR right indicator activated)
	Interaction modality	**Option 2.1: Visual**	**Option 2.1: Visual**	**Option 2.1: Visual**
[illegible]	**Cognitive load**	medium	medium	medium
	Visual load	high	high	medium

	Information based on driver intention?	Information provided **only** if intention of changing lane was detected (driver intention module OR indicator activated)	Information provided **only** if intention of changing lane was detected (driver intention module OR indicator activated)	Information based on detection of LC manoeuvre
	Interaction modality	**Option 3.1** (driver not distracted AND no car on the right): **visual** **Option 3.2** (driver distracted OR cars on the right): **visual + acoustic**	**Option 3.1** (driver not distracted AND no car on the right): **visual** **Option 3.2** (driver distracted OR cars on the right): **visual + acoustic**	**Option 3.1** (driver not distracted AND no car on the right): **visual** **Option 3.2** (driver distracted OR cars on the right): **visual + acoustic**

Table 4: HMI overall concept (information provided and interaction modalities)

Alternative graphics for the adaptive HMI have been designed by using the information provided in Table 4, as shown in Figure 7 and Figure 8, which represent the HMI to support the driver while changing the original lane (Task 1).

Figure 7: Option 1.2.1 (driver distracted), visual and acoustic interaction

Figure 8: Option 1.2.2 (car approaching on the left), visual and acoustic interaction

So far, the activity conducted by REL was meant to identifying the cognitive and visual load of each task to provide appropriate information to the driver (by also considering the most suitable interaction modality to allow the driver processing this information in continuously changing conditions).
Therefore, we mainly focus on the "what", i.e. what the driver should do in each condition (e.g. "keep the lane", "change the lane", etc.).
However, recent studies [53] have shown the importance of providing information on the "why" describing reasoning for actions to achieve better driving experience in (semi-autonomous) adaptive vehicles. The explanation of the "why" also affects the driver's attitude and safety performance.
Therefore, the preliminary HMI concept has been improved in by including innovative communication strategies to describe the "why" in a way that is suitable to the cognitive and visual load of the driver, by also considering additional multi-modal (visual, acoustic, haptic and tactile) interfaces (that will be embedded in the vehicle to complement the information provided by the app).
In particular, alternative HMI concepts and solutions will be developed to provide the information about the "why", e.g. direction haptic feedback in the seat when a car is approaching from the back and the "keep the lane" message is displayed (the haptic feedback intuitively explains that the driver should keep the lane because a car is approaching from behind).
In order to avoid any annoying effect, we planned to provide haptic/acoustic feedback for the "why" (in addition to the visual message) only in case of real danger, where the driver is expected to suddenly react in order to avoid a collision.
Therefore, we identified 3 safety-critical conditions where to provide "why" information with haptic/acoustic signals:

1. When the driver wants to change the lane but a car is approaching on the left (Figure 9)
2. When the driver wants to re-enter the lane but a car is on the right lane (
3. Figure 10)
4. When the driver has to brake in order to avoid a collision with the car ahead (Figure 11)

Figure 9: HMI to support the driver if s/he wants to change the lane but a car is approaching from behind

Figure 10: HMI to support the driver if s/he wants to re-enter the lane but a car is on the right lane

Figure 11: HMI to support the driver when s/he has to brake in order to avoid a collision with the car ahead

For each condition we'll define a set of most appropriate delivery modes to intuitively provide the driver with the "why" information.
Moreover, in order to evaluate this concept and assess the benefit of providing additional haptic/acoustic feedback for the "why" in safety-critical conditions, we plan to conduct experiments in simulation scenarios in

collaboration with SNV (that will provide the experimental design of the tests).
More in detail, one of the issues concerning the effectiveness of each multi-modal message has to do first with the choice of the best channel to perform the task and the subtask and second with the ability to reduce as much as possible interference effects able to slow down the performance and increase the error risk. According to the channel that can be chosen there are different possible levels of interference that can act in a driving task. The first has to do with the modality: verbal vs nonverbal. Any device able to answer to the "why" describing reasoning for actions has to be tested in order to see whether and under which conditions interference can be reduced and avoided. It is well known from the literature that verbal codes can interfere each other in production and comprehension. So far, the choice of the correct lexical items and sentences to alert of an incoming danger can represent a problem given the different semantic effects that can be evoked by words differing for lexical dimensions as frequency of use, imageability, and concreteness. On the other side nonverbal devices have not been sufficiently investigated to be sure that any intra/intermodality device will not interfere with driving. In a series of experiments verbal dimensions and non-verbal dimensions (acoustic, visual, tactile) will be investigated using the classic interference paradigms derived by the Stroop task [54] by assessing intra and intermodality of stimulus presentation and different effectors for the answers. Interference paradigms will be modulated also with respect to the low and high visual processing with particular attention to the first stages of pre-processing until the cognitive load induced by central processing and consequently load.

Appendix B

As an example, fatigue effects can lead to reduced decision making ability and increased reaction time that can lead to failures by the human agent to successfully respond to changes in the current operational context. The more the task performed by the human agent is safety-critical (like the plane operation considered in UC2), the more such a human state represents a dangerous condition. The AdCoS should come into play when high levels of fatigue are detected in the human operator agent, by adapting the driving support provided by means of its interface, i.e., by adapting the content and the way in which the information needed to preserve the pilot situation awareness is provided to the operator. The communication strategy needs to contrast the fatigue of the operator to deliver the necessary message in a timely and effective way.

Let us consider as another example the automotive use case UC4. Besides assessing the external environment context (road, traffic, obstacles, other vehicles, etc.), the AdCoS needs to correlate both the distraction state of the operator with his detected intention (i.e., the evaluation of the maneuver the driver is going to perform) in order to assess the risk of the current driving situation and to provide accordingly warnings or action suggestions. When in case of a detected visual distraction, the driver is not currently looking on the road ahead and critical information about the external environment may be not perceived. If in case of a lane changing maneuver, such critical information may determine AdCoS actions that can lead from warning the driver to the inhibition of the dangerous maneuver. By considering the visual load of the operator, other communication channels for providing both the performed adaptation and the motivation of the adaptation need to be carefully considered.

Appendix C

1. Guideline #1: Preattentive attributes examples

The preattentive attributes of visual perception can be organized into four categories: color, form, spatial position and motion. A summary of these attributes can be found in the following graphic:

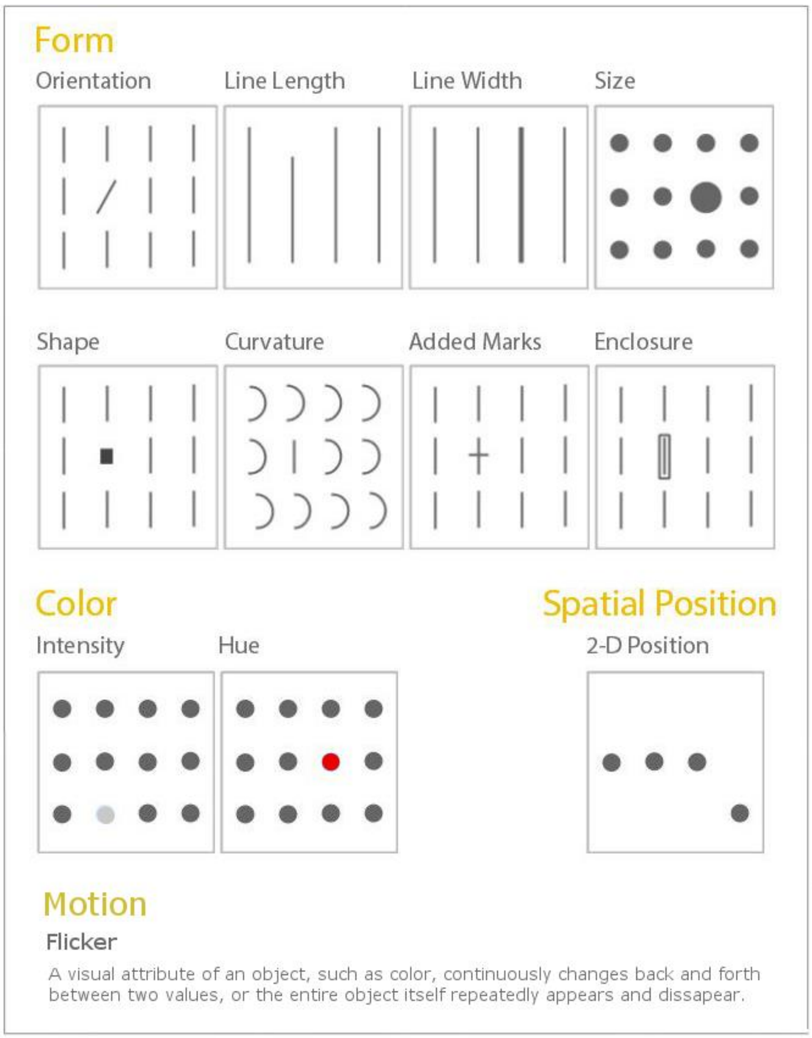

Figure 12: Preattentive attributes of visual perception

These attributes come into play when we analyze any visualization. Of this list, only ***Position*** and ***Length*** can be used to perceive *quantitative data* with precision. The other attributes are useful for perceiving other types of data such as categorical or relational data.

1.1. Attributes of Form

For example, both the pie chart and the bar chart below show the same data. But you can’t easily tell from the pie chart which is the biggest pie. Our inability to reliably compare the size of 2D areas makes pie charts difficult to interpret. That is more clearly visible in the bar chart as it calls on the preattentive attribute of length.

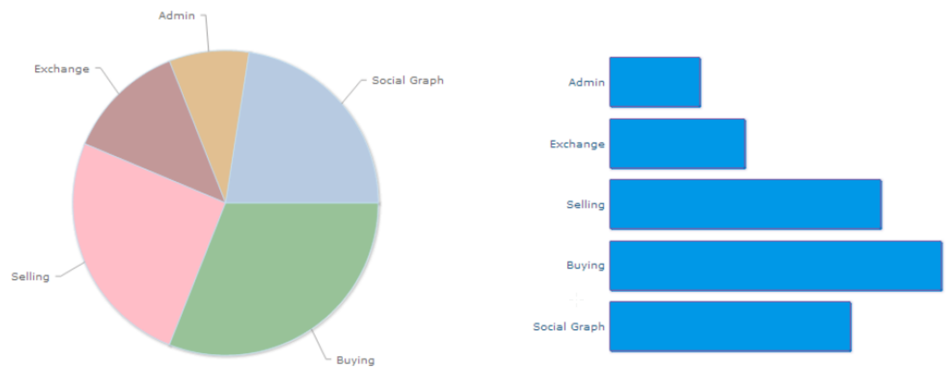

Figure 13: Size attribute is badly used to describe quantitative data

In dashboard design, the attribute of ***line length*** is most useful for encoding quantitative values as bars in a bar graph. Line width, on the other hand, can be useful for highlighting purposes. You can think of ***line width*** as the thickness or stroke weight of a line. When lines are used to underline content or, in the form of boxes, to form borders around content, you can draw more attention to that content by increasing the thickness of the lines.

The ***relative sizes*** of objects that appear on a dashboard can be used to visually rank their importance. For instance, larger titles for sections of content, or larger tables, graphs, or icons, can be used to declare the greater importance of the associated data.

Simple shapes can be used in graphs to differentiate data sets and, in the form of icons, to assign distinct meanings, such as different types of alerts. Added marks are most useful on dashboards in the form of simple icons that appear next to data that need attention. Any simple mark (such as a circle, a square, an asterisk, or an X), when placed next to information only when it must be highlighted, works as a simple means of ***drawing attention***.

Last on the list of form attributes is ***enclosure***, which is a powerful means of grouping sections of data or, when used sparingly, highlighting content as important. To create the visual effect of enclosure, you can use either a border or a fill color behind the content.

1.2. Attributes of Color

One of the interesting (but hardly intuitive) things about color is that we don't perceive color in an absolute way. What we see is dramatically ***influenced by the context*** that surrounds it. Take a look at the gray squares in Figure 14. They appear to vary in intensity, but in fact they are all exactly the same as the lone square that appears against a white background at the bottom.

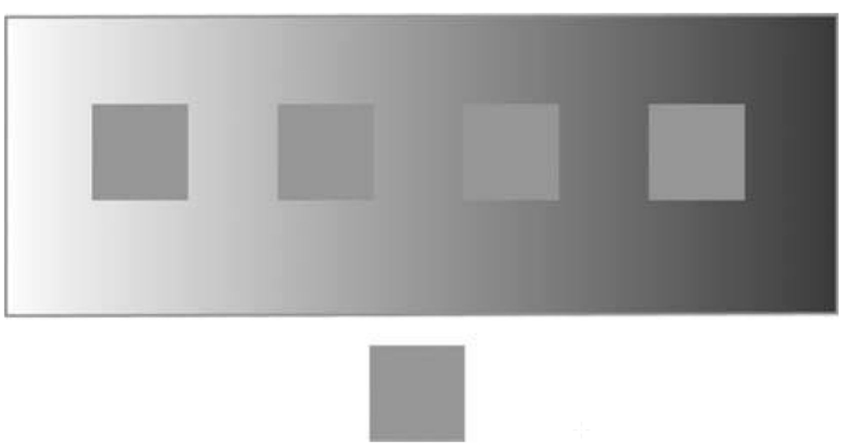

Figure 14: Context affects our perception of colour intensity

Color must be used with a full awareness of context. We not only want data to be fully legible, but also to appear the same when we wish it to appear the same and different when we wish it to appear different.

On the other side, color intensity, such as different shades of gray ranging from white to black can be quantitatively perceived to a degree (by making one value darker, for example, we can tell that is greater than another). But not well enough to decode specific shades into specific values.

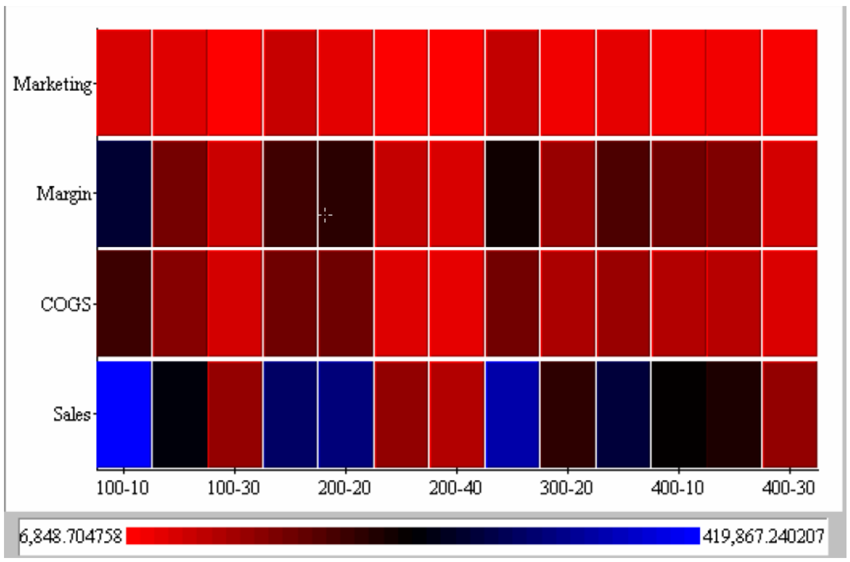

Figure 15: Example of a misuse of hue for the display of quantitative values

Another example on how the preattentive attributes do their job of grouping two datasets in a scatter plot. We have ***orientation*** on the left and ***hue*** on the right. Which of them does a better job? They both work to a degree, but hue works better.

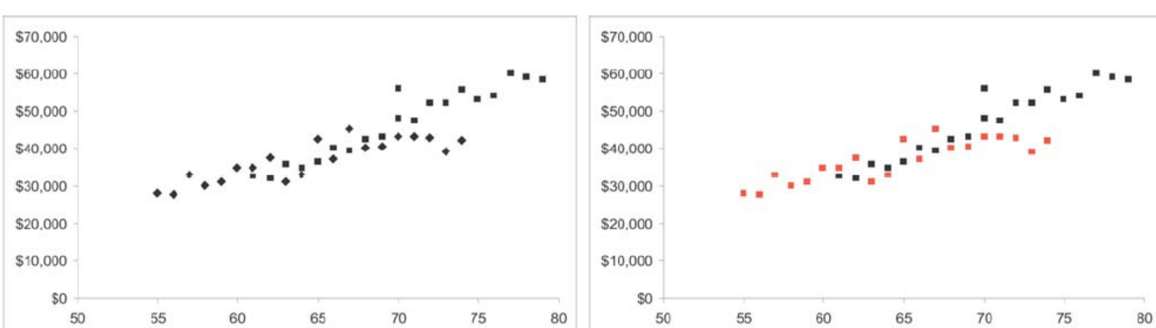

Figure 16: Comparison of the relative strength of orientation and hue

1.3. Attributes of Spatial Position

The preattentive attribute 2-D position is the primary means that we use to encode quantitative data in graphs (for example, the position of data points in relation to a quantitative scale). This isn't arbitrary. Of all the preattentive attributes, differences in 2-D position are the easiest and most accurate to perceive.

In Figure 17 is shown an example of ***2D position*** of documents. It has the advantage to map properties of the underlying document data on the two axes. It is easily to find most relevant documents and most important. On the other side using position to visualize makes difficulty to select documents with same relevance factor. Solution to this to avoid occlusion of documents is to translate them on one of the axes, inhibiting the mapping of a second property axis.

Figure 17: Left side: less important documents are tilted away from the user. Right side: effect of colour and intensity is used

1.4. Attributes of Motion

Flicker refers to an element that appears and disappears. This pattern is normally measured in cycles per second, the frequency of repetition. For example, flicker was chosen as the means to help us locate the cursor because it is a powerful attention-getter.

Although flickering objects on a screen can be quite annoying and thus should usually be avoided. Still, there are occasions when flicker is useful. This is especially true for dashboards that are constantly updated with real-time data and are used to monitor operations that require immediate responses.

2. Guideline #2: Gelstat principles examples

Gestalt principles describe how our mind organizes individual elements into groups. We can use these principles to highlight patterns that are important, and downplay other patterns. The image below illustrates the principles of Gestalt which are relevant to visualization.

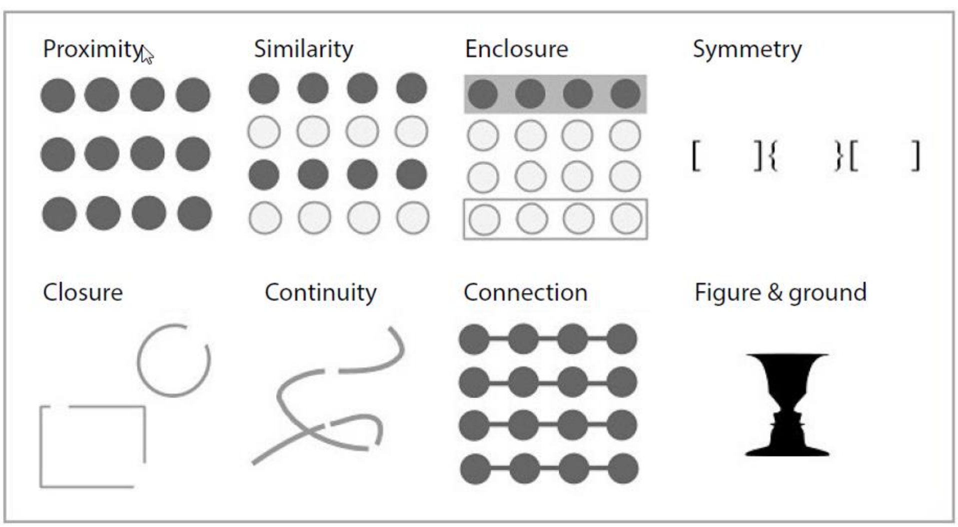

Figure 18: Gelstat principles relevant for visualization

An explanation from each of the illustrations:

- *Proximity:* We see three rows of dots instead of four columns of dots because they are closer horizontally than vertically.
- *Similarity:* We see similar looking objects as part of the same group.
- *Enclosure:* We group the first four and and last four dots as two rows instead of eight dots.
- *Closure:* We automatically close the square and circle instead of seeing three disconnected paths.
- *Continuity:* We see one continuous path instead of three arbitrary ones.
- *Connection:* We group the connected dots as belonging to the same group.
- *Symmetry:* We see three pairs of symmetrical brackets rather than six individual brackets.
- *Figure & ground:* We either notice the two faces, or the vase. Whichever we notice becomes the figure, and the other the ground.

A good example of using the Gestalt principles to communicate information in a visual way is the following visualization that compares the mentions of Apple, Google and Microsoft across the Web.

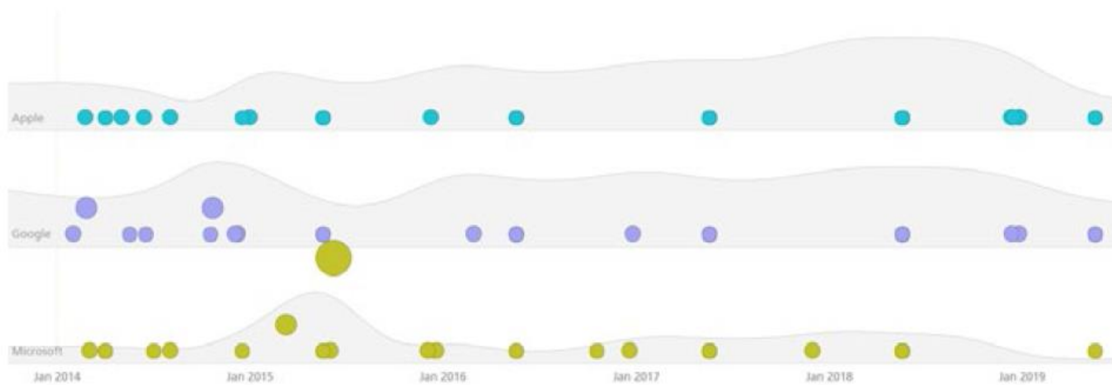

Figure 19: Good visualization example following the Gelstat principles

This visualization features two chart types - An area chart, which is grayed out in the background, and a bubble chart, which is color-coded in the foreground. Let's analyze this simple visualization, and identify which elements from this guideline it uses:

- *Figure & ground:* The first thing noticed when looking at this visualization is that the bubbles stand out against the backdrop of the area charts. This shows the Gestalt principle of figure & ground.
- *Proximity:* Zoning in on the bubbles shows 3 distinct groups of bubbles. We can identify this easily because of how close the bubbles are to each other.
- *Similarity:* Further, we notice that the bubbles are of three colors - green, purple, and blue. This similarity brings out the grouping even more clearly.

Furthermore, linking with the previous guideline related to **preattentive attributes**, we can also analyze some of them in the visualization:

- *Spatial position:* the preattentive attribute of position is used to track the rise and fall of the area chart. Similarly, we notice the abnormal bubble in Microsoft's chart because of its higher position compared to the other bubbles.
- *Size / Area:* The bubbles vary in size. Their size corresponds to the number of web mentions for a particular topic. This makes it easy to spot the important mentions, and explore them in detail.
- *Hue / Color:* As mentioned earlier, the color of the bubbles makes it easy to classify them into three groups. This employs the preattentive attribute of Hue.
- *Intensity:* Finally, the low intensity of the area chart places it in the background, giving priority to the bubbles.

3. Guideline #3: Display the data as clearly and simply as possible

In 1983, Edward R. Tufte introduced the concept of "data-ink ratio" in the book The Visual Display of quantitative Information. When quantitative data is displayed (mainly in printed form), some of the ink that appears on the page presents data, and some presents visual content that is not data (a.k.a. non-data).

Tufte defined the data-ink ratio in the following way:

"A large share of ink on a graphic should present data information […]. Data-ink is the non-erasable core of a graphic, the non-redundant ink arranged in response to variation in the numbers represented. Then:

Data ink-ratio= data-ink / total ink to print the graphic"

This is to say 1.0 – proportion of a graphic that can be erased without loss of data-information. The nearer this data ink-ratio is to 1.0, the more accurate this guideline is followed.

This principle can be extended to computer screens, and the term "ink" can be changed to "pixels".

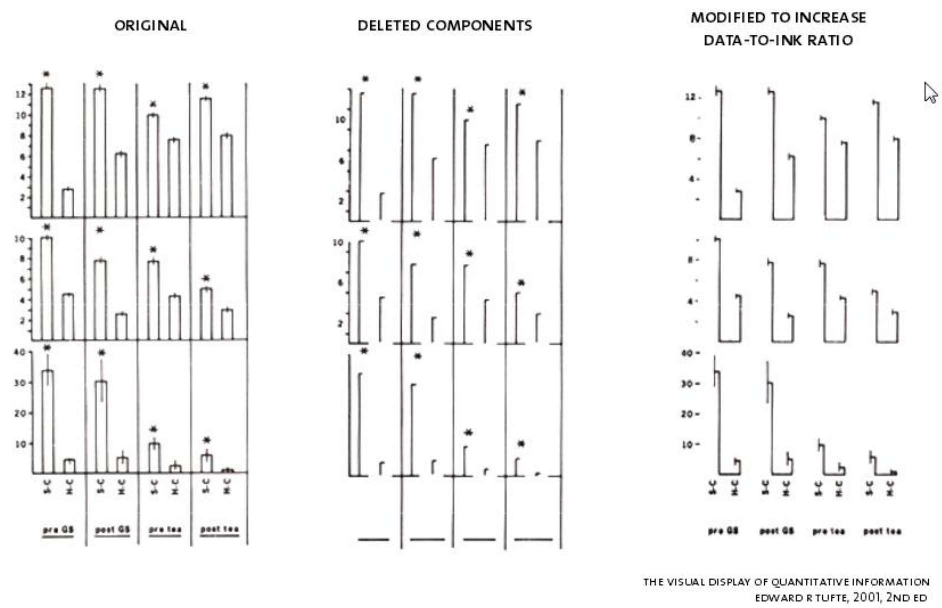

Figure 20: Example on how to simplify data to ink-ratio

So reducing the non-data pixels to a reasonable minimum is a key objective that places us on the path to effective visual communication. Much of visual communication design revolves around two fundamental goals:

- Reduce the non-data pixels

- Enhance the data pixels

3.1. Reduce the non-data pixels

The next figure provide one example of non-data pixels that often appear in a screen but can usually be removed without loss.

One few operative ink-ratio could be the variations in colour that don't encode any meaning, as in figure X:

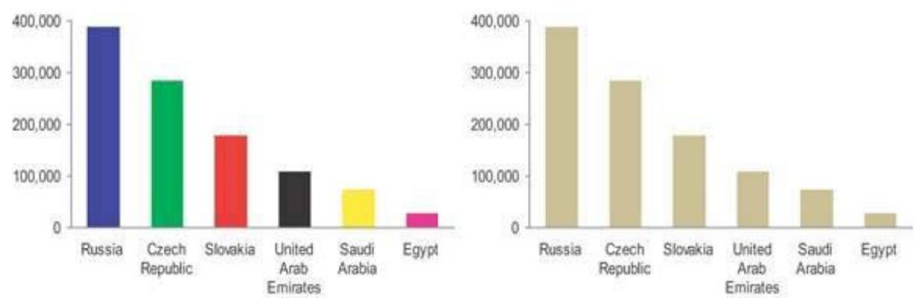

Figure 21: Example on how to eliminate bars varying in colour for no meaningful reason

Another bad example of non-operative ink-ratio is using the 3D in graphs when the third dimension doesn't correspond to actual data:

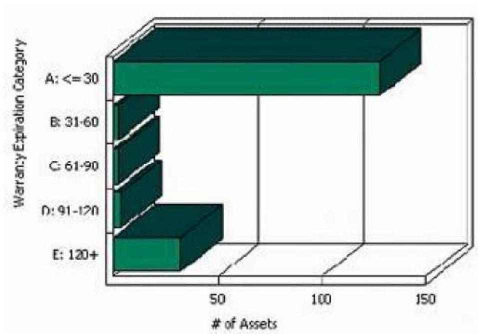

Figure 22: 3D should always be avoided when the added dimension of depth doesn't represent actual data

Visual components or attributes of a display medium that serve no purpose but to make it look more like a real physical object or more ornate:

Figure 23: Visualization filled with visual components to simulate real physical objects

3.2. Enhance the data pixels

All the information that is shown in visualization should be important, but not all data is created equal: some data is more important than other data. The most important information can be divided into two categories:

- Information that is *always* important
- Information that is only important *at the moment*

These two categories of important information require different means of highlighting on a screen. The first category information that is always important can be emphasized using ***static means***, but the second category information that is important only at the moment requires ***dynamic means*** of emphasis.

The location of data on the screen the layout is an aspect of a dashboard's appearance that doesn't, or at least shouldn't, change dynamically (because after some use viewers will come to expect specific data to appear in specific locations). Because location is static, this is a variable that we can leverage to highlight information that is always important.

Few aspects of visual design emphasize some data above the rest as effectively as its location. Figure 24 identifies the emphasizing effect that different regions of a dashboard provide. The top-left and center sections of the dashboard are the areas of greatest emphasis. Contrary to the influence of reading conventions, however, the very center of the screen is also a region of strong emphasis, due to a more fundamental inclination of visual perception.

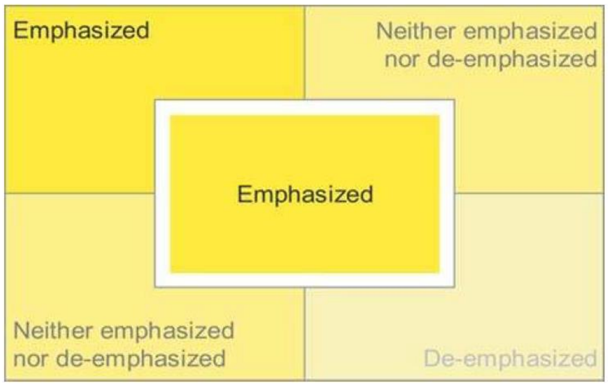

Figure 24: Different degrees of static visual emphasis

Visual attributes other than location on the screen are usually easy to manipulate in a dynamic manner on a dashboard. As such, dynamic techniques can be used to highlight information that is of great importance only at particular times. Many of the visual attributes examined in Guideline#1 and Guideline#2 can be used effectively to highlight data, both statically and dynamically. Here are two approaches that can be taken:

- Use expressions of visual attributes that are greater than the norm (for example, brighter or darker colors).
- Use expressions of visual attributes that simply contrast with the norm (for example, blue text when the norm is black or gray).

Color is especially useful because distinct differences in color stand out very clearly and because it is a variable that is normally easy to change dynamically using dashboard software based on predefined data conditions.