INTEGRATING VISUAL STIMULI INTO AUTOMOTIVE HEAD-UP DISPLAY
TO ENHANCE DRIVER PERFORMANCE

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ABSTRACT

For the past few years, vehicular informational hardware and software artifacts started incorporating massive amounts of information and became more complex. Despite their ability to occasionally increase mobility and help the driver, they can also constitute a serious threat to the driving task, putting safety at risk. As the amount of information increased, the driver's ability to interact with the artifacts and concurrently process information related to the vehicle control declined.

This study aims at discussing the design of automotive head-up display and proposing a methodology to design more efficient in-vehicle artifacts. To achieve its objectives, drivers, artifacts and environment are studied and systematized as variables of a structure that is relevant to the driving task. This research document is based on literature review.

The findings of this essay show that the efficient use of visual communication can improve head-up displays design. Thus, it should enhance the driver's ability to control the vehicle while interacting with it.
This essay also demonstrates that to plan and design effectively for this media, a designer should encompass a better understanding of the interaction between users, artifacts and environments to overcome their individual and collective limitations.
DEDICATION

To Malu

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ACKNOWLEDGMENTS

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LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO – American Association of State Highway and Transportation Officials
ACC – adaptive cruise control
AMLCD – Active matrix liquid crystal display
ATIS CVO – Advanced Traveler Information Systems/Commercial Vehicle Operations
ATX – ATX Technologies, Inc. Irving, Texas.
CAN – Automatic Crash Notification
CDS – Crash Worthiness Data System
C-MOS camera mounted inside the front window
CMS – Collision Mitigation Brake System
CPU – Central Processing Unit
CWS – Collision warning system
Deg. – degrees
F1 – Formula One
FFP – Free from prism
GMNA – General Motors North America
GPS – Global Positioning System
HCI – Human-Computer Interaction
HDD – Head-Down Display
HiDS – Honda Intelligent Driver Support
iHMD – Helmet-mounted Display
HUD – Head-up Display
IHCC – Intelligent Highway Cruise Control
ITS – Intelligent Transportation Systems
LKAS – Lane-Keeping Assist System
LTM – Long-Term Memory
MMI – Multi Media Interface
NASA – National Aeronautics and Space Administration
NASS – National Accident Sampling System
OEM – Original Equipment Manufacturer
SAE – Society of Automotive Engineers
STM – Short-term Memory
STSS – Short Term Sensory Store
SWAT – Subjective Workload Assessment Technique
TE – Time Evaluation
TLX – Task Load Index
TSP – Telematics Service Provider
VRM – Vehicle Relationship Management
XM – XM Satellite Radio Holdings Inc. Washington, D.C.
CHAPTER 1

INTRODUCTION

The evolution of technology
Since the birth of computational machines, storage and electronic devices have been improved in terms of switching speed and storage capacity. “Further increases in speed are being studied and implemented through the use of materials other than silicon, such as gallium arsenide and alloys of silicon and germanium” (Card et al. 1983). As processing capacity increased, the size of computational devices decreased. Also, software development made computers faster and more capable of performing a wider, more complex variety of tasks.

As systems become more powerful, with smaller and more powerful microchips, circuits and processors have expanded the technological evolution beyond the desktop computer. Like in many other fields, technological evolution has also affected the automotive environment. Recently, more car manufacturers have started commercializing automobiles with hardware and software artifacts that are capable of accommodating enormous amounts of information.
The design tradeoffs between aesthetics, novelty and usability became more obvious as the in-vehicle artifacts presented a growing quantity of information to the driver.

**Marketing design**

The introduction of new complex systems increased car sales, pushed by consumers motivated by the novelty element. “Factory-to-dealer sales of mobile video and navigation devices amounted to more than $450 million in 2002, a 54% jump from 2001, according to the Consumer Electronics Association. Americans bought 800,000 rear-seat entertainment systems and 300,000 navigation units. XM Satellite Radio, which went nationwide just 18 months ago, has some 500,000 subscribers, and the company expects to reach 1.2 million by the end of 2003. And it’s not just luxury-car owners who are shelling out for the high-tech extras. New-car buyers can find options like these on everyday models, such as a $25,000 Honda Accord, or a $22,000 Pontiac Vibe.” (Hamilton, Time Magazine, 2005)

In first glance, the aesthetics were improved and the dashboard area simplified. The general trend was the combination of several car controls into one physical knob and a screen display. Although novelty and aesthetics were improved, the overall usability of the systems decreased, and the ability of the driver to interact with it while performing the primary task – driving – became severely limited.

Automotive powerful computational hardware and software are no longer exclusive to early adopters. Different functions are constantly inserted into car artifacts. The perceived value of one product is directly related to the number of functions it carries. Assuming companies will pursue sales increase, we can expect to see a growing number of functions added to car systems.
The problem of complex artifacts

"The evolution of computers has made a variety of in-vehicle information systems possible. These new information systems can enhance mobility, but they may also distract drivers and undermine safety" (Lee et al, 2000). Despite their ability to occasionally help the driver, complex artifacts can also constitute a serious threat to the driving task, putting safety at risk. As the amount of information increases, the driver’s capacity to perceive them and concurrently process information correlated to vehicle control declines.

BMW was one of the first automakers to release a commercial artifact with more than 700 functions embedded into it. The iDrive system is a single-point multitool that combines affordances from knobs, joysticks and a mouse, located at what designers call the “sweet spot”, the place between the front seats where the driver’s right palm naturally comes to rest. It is an easy-to-reach knob that allows the driver to navigate through an interface presented on a central dashboard mounted digital screen. To plot a course through the interface presented on the screen, the user can interact with the knob in three different ways: by rotating, clicking or moving it.
This adaptable system controls the action inside the digital screen, populated by some 700 of the automobile’s secondary functions. The iDrive haptic multicontroller can be made to feel differently when operators or drivers search through its eight main menus such as navigation, music, telephone, and climate - than when they search among items within a menu, giving the user an indication of the currently chosen operational mode.

Despite the effort to improve input methods, BMW’s iDrive computational system complexity can lead to a certain level of frustration for some users. Drivers were reportedly forced to pull over and look at the manual to be able to dial in a radio station while driving the BMW 745i equipped with an iDrive. Dealers are spending around two hours teaching new owners how to navigate the system. (Newsweek Magazine, 2002).
One of the interpretations that can be given to automotive accident statistics is directly related to distraction, which can be substantially increased with the presence of more complex in-vehicle artifacts. Complex systems can deviate the drivers' attention from important events outside the vehicle, contributing to the attention problem. "The accident statistics suggest that a large percentage of the accidents could possibly be prevented if all of the involved drivers were attentive to the critical events immediately preceding the accident". (Shinar, 1978)
CHAPTER 2

HYPOTHESIS

How can design of in-vehicle informational interactive systems be used to enhance interaction between humans and computational machines in the automotive environment? This research proposes that the efficient use of design elements, built upon a better understanding of the interaction between driver, artifact and environment can enhance the driver’s ability to control the vehicle.
OBJECTIVES

This study discusses in-vehicle informational systems to observe possible design improvements, based on present and/or future problems identified through literature review.

The discussion tries to pinpoint the causes of problems and proposes alternatives to the design of in-vehicle systems that incorporate human factors and usability methods.

Also, this document organizes the information available in literature for future references, examining and integrating related disciplines like HCI and Cognitive Psychology to the Design body of knowledge, and investigates the application of Industrial Design principles into Visual Communication Design.

This study aims at demonstrating the need for designing displays that can enhance the driver's ability to stabilize, control, and navigate the car, while proposing a framework to design systems that deliver useful and usable information at the appropriate time.
METHODOLOGY

To achieve its objectives, this essay will establish a scheme exploring the relations between users, the artifacts and the surrounding environment, and how each one of them will change the interaction process between themselves.

This research document is based on literature review and discussion of the findings through Visual Communication Design and Cognitive Psychology perspectives.

This research will use Psychology principles to depict the driver as an information processor. Illustrate the driver's physiological and psychological capabilities and limitations to perceive, process and respond to presented information while interacting with the in-vehicle artifact and controlling the vehicle. Reference will be made to several primary researches that were developed, mainly from a user-centered perspective.

In order to explicate artifacts characteristics and their role on the interaction process, actual technology will be laid out, and contemporary automotive artifacts will be analyzed and presented as part of the driving system.
A picture of the automotive environment will be painted to explain how it affects humans’ driving performance and artifact’s design, its constraints, rules and demands.

Figure 2: A simplified block diagram of the driver functions in the driver-vehicle-road system. (Shinar, 1978)

A framework will be considered to explicate the operation of the scheme. In order to design an effective interactive system, these are the three basic elements that the designer has to better comprehend: (1) users - represented by the drivers, (2) artifacts - automotive informational artifact - and (3) environment - immediate surroundings - enclosing the vehicle and the driver.

This system operates in cycles. The environment changes and presents new stimuli while the vehicle and its driver are in motion. The driver perceives this new information, processes part of it and reacts accordingly. The driver’s action and input from the environment modifies the automotive informational system.
For research purposes, three main elements were considered to affect the interaction process: the user, the system design and the environment. To better understand the study object an interactive cycle based on these three elements will be applied.

It will lay out facts about technology evolution and elements that lead to the conception and production of complex in-vehicle interactive systems. It will also demonstrate through literature review the shortcomings of ITS based on psychological and physiological characteristics of users.

This study is based on secondary research focused on literature review. Three main fields of knowledge will be referred to: Design, Cognitive Engineering, and Psychology.

Design principles will be combined with HCI and Cognitive Psychology theories and applied in an automotive context. Human-Computer Interaction models will be used to describe and predict human behavior. Design elements such as text, colors, shapes, motion, context, tactile and audible elements will be applied to understand how they can label, measure, represent and display information. Human-Computer Interaction models will be used to predict human performance/behavior and understand how the variables - Design principles, human and environmental characteristics –will affect performance.
Cognitive Psychology will be relevant to understand the effect of learning and retrieval during the interaction process.

This document will draw a line around the scope of this research. We defend that there is a universal theoretical framework for interactive processes composed by users, systems and environments. We prove that to design better interfaces we have to know how users perceive, understand and react to different stimuli. Also, that different environments will impose different demands to the driver. The artifact - hardware and software system - will also impose technical constraints to the design. Finally that the use of shapes, colors and text in given orientation, motion, proportion has to be designed based on users perception and cognition, environmental demands, and artifact’s constraints and capabilities.
CHAPTER 3

UNDERSTANDING ENVIRONMENT, DRIVERS AND IN-VEHICLE ARTIFACTS

This research is based on the principles of iterative design approach, also proposing that designers have to know what the problem is, understand users, artifacts and environments while designing.

Improving driving could be linked to several different methods. Improving drivers licensing methods, driver training, car mechanics, roadways, etc. This study will layout information about the environment and the drivers to better discuss issues related to the system design.
Environment, Drivers and Systems

To investigate this problem, and better understand the system design, this research will utilize a scheme similar to the one presented in figure 2. This scheme incorporates the three main elements that participate in this process: Driver, Environment and Vehicular Artifact.

![Diagram of Environment, Driver, and Artifact](image)

**Figure 3.** Framework composed by Driver, in-vehicle hardware and software Artifact and Environment. (Adapted from Shinar, 1978)
Considerations drawn on the in-vehicle screen-based interface design will be directly affected by the individual characteristics of those three elements as well as the interactions between them.

**Environment**

For this research, environment will be considered as the group of conditions of the natural world, along with all the external factors “that surround people and affect the way they live” (Encarta World English Dictionary, 1999). The environment will define how the vehicle should be controlled by the driver, as well as the conditions in which the interactions will occur. It presents the paths through which the vehicle will navigate as an infinite and continuous amount of information for the driver. To better understand the different effects and interactions between the environment, driver and artifact, it was divided into two different categories: the setting inside the vehicle, and the world that surrounds the vehicle.

**Vehicle Interior**

Inside the vehicle there is a number of physical controls: steering wheels, brake and accelerator pedals, mirrors, seat, radio/CD player, instrumental gauge, emergency brake lever, etc.
The cockpit’s main objective is to present controls that allow the driver to be in command of the vehicle. Instrumentation – software and hardware artifacts – will share real estate with the controls and display information to the driver.

Vehicle surroundings
External environment is composed by the immediate elements that surround the vehicle. The infinite and continuous amount of information is constantly changing. In the majority of the situations, the car is surrounded by various physical elements.
Selection of speeds, paths, and other decision-making actions are dependant on the drivers being able to perceive the road and the physical elements around it. "Drivers must see the road directly in front of their vehicles and far enough in advance to predict with a high degree of accuracy the alignment, grade, width, and related aspects of the roadway. The view of the road includes its immediate environment. Such appurtenances and obstacles as shoulders, sign supports, bridge piers, abutments, guardrail, and median barriers that affect the driver must be clearly visible." (AASHTO, 1984)
Also, the conditions in which the surrounding physical elements are inserted will affect greatly the driving related tasks. In different conditions, not only the vehicle will behave differently, but also the visibility might impose additional obstacles to the driver.

Physical characteristics and conditions of the immediate vehicle surroundings will define the interaction between the driver and the controls inside the vehicle in order to control it. These interactions will be translated into tasks that the driver has to perform to control the vehicle, thus, achieve the final goal – to get to the destination.

Environmental Demands

The environmental demands will vary over time. Depending on how complex the information presented by the environment is – e.g., number of lanes, angles on curves, number of other cars sharing the road – they will require more or less from the driver.
Figure 6. The interaction between the environmental demands and driver performance levels. (Shinar 1978)

The environment will present a continuous flow of information to the driver. The vehicle speed and the environment’s visual complexity will determine the amount of information that will be presented to the driver in a given amount of time. Figure 6 shows a graphic with qualitative information regarding driver’s performance and the environmental demands. The dotted line, representing environmental demands reflects the complexity of the problem that the driver has to solve in order to interact with the environment. This graphic suggests that accidents are prevented as long as driver’s performance level is maintained above environmental demands level. Point A illustrates a congested high-speed driving scenario, where the rate of information presented is high. Aware of the situation, the driver is focused on the task, and is able to increase his performance in
response to the environmental demands. As moving to point B, the demands from the environment declined. It could have happened because either the environment is less complex or because the driver slowed down—slowing the rate of data that he/she has to process in a given time. The less demanding environment allows the driver to allocate much of the information processing capacity to non-driving tasks.

The result is a drop in performance, although that is still enough to control the vehicle securely. "A characteristic common to most emergency situations is that they place high demands on an unprepared driver—leading to the situation depicted on point C in which two curves cross each other, and an accident results." (Shinar, 1978)

As discussed, environmental demands change over time, depending on the complexity of the combination between physical elements, the conditions they are inserted in and the rate in which they are presented to the driver. The question remaining is related to what makes driver's performance fluctuate over time.

**Driver**

The driver is the most important element of the scheme presented on this research. Drivers are the decision-making elements, the ones in control of the vehicle. Driver's performance will vary depending on their individual psychological and physiological characteristics.
Figure 7. Schematic model of influences on cognitive processes. (Nisbett 2003)

The broader environment in which the person is inserted shapes individual characteristics, and ultimately their cognitive processes. While going from global to local, social, economical and cultural spheres will form the dimensions of mental and physical processes on each one of us. This infinite number of elements also shapes driver’s interactions with the environment, based on cognitive processes. Since the arrangement of these elements is not likely to produce a similar combination to two different people, they are likely to form different cognitive processes. These individual
differences are to be considered, but will not be further investigated in this research. To better cope with the problem, it will consider a "universal" model of cognition to explain the driver’s interactive cycle phenomenon.

**Perception, Information Processing and Response**
To be able to better understand how drivers interact with artifacts and environment, considerations on human information processing is crucial. Several distinctive theoretical approaches described different models of human performance. They vary from specific to general, qualitative to quantitative. For this research, the general qualitative model (Wickens 1992) will be utilized, and adapted for auxiliary exploration.

Although summarized here, this model explains clearly the stages of information processing that will be important for us to understand the foremost potential limitations on driver’s performance that will affect the characteristics of the artifact design.
Figure 8. A general qualitative model of human information processing. (Wickens 1992)

As seen on Figure 8, Wickens divided the process into six distinctive phases. (1) Sensory Processing is related to the "unique limitations on each sensory system influence the quantity and quality of information that may be initially registered and so, potentially, all processes that follow." Each sensory system, or modality, appears to be equipped with a central mechanism of (2) Short-Term Sensory Store that prolongs a representation of the physical stimulus for a short period of time after the stimulus has physically terminated. It's known to be preattentive, relatively veridical and rapidly decaying. During the (3) Perceptual Encoding phase, STSS preserves the details of the stimulus image only briefly and without attention. The information is then processed by
progressively higher centers of the nervous system. As it makes contact with a unique neural code that was learned and stored in the brain, the stimulus is said to be perceived or recognized. The result is a perceptual decision in which the physical stimulus is assigned to a single perceptual category. Once the stimulus has been perceptually categorized, the operator moves to the (4) Decision Making and Response Selection phase, where he/she must decide on what to do with the stimulus. The decision can be careful, thoughtful, or rapid and nearly automatic. A large degree of choice is involved, and heavy potential costs and benefits depend on the correctness of the decision. If a decision is made to generate a response, an added series of steps is required to call up, and release with the appropriate timing and force, the necessary muscle commands to carry out the action, during (5) Response Execution. (6) Feedback and Information Flow is related to the act of monitoring the consequences of our actions, forming the closed-loop feedback structure depicted in Figure 8.

Although the interaction is a continuous process, and the majority of its phases happen concurrently, it will be presented here as containing three major distinctive stages associated to driving.
Figure 9. Simplified model of driver information processing

The model on Figure 9 presents a continuous and cyclical process, where information is presented from both the environment and the artifact. In order to respond to this information, the driver interactive cycle will be divided into three phases. The three main distinctive interaction phases presented here are Perception, Decision-Making and Response. Despite illustrated as three separate stages, it is important to note that the occurring mental processes within each one of them are occasionally overlapping phenomena.

Perception

Perception is related to the use of different senses to acquire information about the surrounding environment and its events. Audition and vision are the two most frequently used sensory channels by humans to obtain information from the environment.
“Somesthetic sensing, i.e., touch, temperature, and pain; the sense of smell, the sense of balance or vestibular sense; plus sensations of position and movement or kinesthesis, also contribute to a knowledge of the immediate environment.” (Van Cott et al, 1972).

Contemporary research point out the importance of different senses, but few would dispute the importance of vision in the driving task. The vast majority of information required for driving is obtained through the visual system (Bossi et al, 1996). The predominant mode of driver-environment interactions is visual. Inferences related to the direction of the road ahead, the position of the car in the lane, and the behavior of other drivers are all conveyed visually (Shinar, 1978). To be able to control the vehicle effectively, the driver has to be able to perceive visual cues that are relevant.

**Visual Perception**

Two elements are most important when relating to visual information. The first is related to the nature of the cues that the environment presents to drivers, and the second to the amount of information that the driver can process visually at a time.

**Nature of the visual cues**

In most natural situations, the visual information available about the distances to various objects is strongly redundant. In textbook treatments of distance perception, it is common to see lists of distance cues, all of which are normally available simultaneously, and all of which normally lead to the same answers about the distances to various objects. Various ways of classifying these cues have been used, including
such categories as binocular cues, physiological cues, kinetic cues, and oculomotor cues. For present purposes, the classification that is most useful is the division into pictorial and nonpictorial cues. Pictorial cues are simply those that can be depicted in a two-dimensional representation, or picture.

**Pictorial cues**

Many pictorial distance cues have been identified and discussed, sometimes in slightly different forms by different authors. Kaufman (1974) lists the following items under his discussion of pictorial cues: perspective, detail perspective, size and retinal image, aerial perspective, relative brightness, light and shade, and interposition.

![An illustration of various pictorial distance cues.](image)

**Figure 10.** An illustration of various pictorial distance cues.

*Figure 10.* which is modeled on a straight, level road, depicts several such pictorial cues. “One cue that is often mentioned, but that does not appear in the listing from
Kaufman, is height in the visual field. Consider the four rectangles in Figure 19, which may be seen as four vertical panels, all about the same size, at four different distances along the right edge of a schematic roadway. Several pictorial cues indicate the relative distances to each of the panels. Assuming that the four panels are the same actual size, the different image sizes of the four panels indicate their relative distances from the observer. The pattern of interposition that is portrayed in the figure conveys the same information about relative distance (although only at an ordinal level rather than a ratio level). Height in the visual field is also in agreement. Consider the elevations of the bases of the four panels. Panels with smaller image sizes, and panels that are further down in the chain of interpositions portrayed, also have bases that are higher in the visual field.

The validity of height in the visual field as a cue to distance depends on the assumptions that objects are resting on a single, reasonably flat plane, and that the plane is below the point of view of the observer. One or both of these assumptions is probably violated in much everyday experience. In a typical indoor environment, there may be multiple horizontal surfaces at different elevations, such as floors, table tops, and shelves, as well as vertical surfaces, such as walls. Objects are commonly mounted in rather arbitrary locations on these surfaces, including being hung on walls or from ceilings. In many natural outdoor environments there is also no simple, horizontal support surface. The ground may be hilly, and foliage may obscure major portions of the terrain. In contrast to these rather complex worlds, the roadway environment is simple and predictable. In particular, moving objects (vehicles, pedestrians, etc.) are almost always supported by a single surface that is for the most part unobstructed for considerable distances, and that is flat to a very good approximation within a reasonable range of distance” (Flannagan 2000).
Nonpictorial cues

<table>
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<th>Nonpictorial Cues</th>
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<td>Accommodation</td>
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*Table 1* Nonpictorial Distance Cues (Flanagan et al, 2001)

*Table 1* lists nonpictorial distance cues. The two forms of binocular cues both depend on the vergence of the eyes, but in slightly different ways.
Figure 11. Distance from the object is calculated through angle of vergence.
(Hershenson, 1999)

As illustrated in figure 11, the distance is calculated roughly through the distance between the eyes (A), the object (D) and the angle between them (γ). Convergence applies to a single object that is imaged on the foveas of both eyes. The angle of
vergence, along with the distance between the two eyes, then specifies the distance to that single object. The critical information for binocular disparity is in a slightly different form. Binocular disparity refers to the slight difference in the positions at which an object will be imaged on the right and left retinas depending on whether it is just beyond or just in front of the distance at which the eyes are converged.

Accommodation is related to the inability of the human eye to focus on stimuli that are displayed in different distances. Driver's perceptual system uses the cue of different focal points to infer that the objects are in different distances.

Figure 12. Accommodation illustration: the sign is focused on the retina. The car, in a different distance is blurred.
Figure 13. Accommodation illustration: the car is focused on the retina. Other cars and the sign, in a different distance are blurred.

As illustrated in figures 12 and 13, different distances correspond to different focal points. In order to keep the image of an object sharply focused on the retina, the lens of the eye must change shape slightly depending on the distance to the object. Objects at other distances, both nearer and further away, will appear blurred.

Motion parallax due to translational movements of the observer or the observer's head provides information about the distances to surrounding objects. For closer objects, a given amount of translation of the point of view will cause a larger change in angular location than for more distant objects. In a two-dimensional, camera-based display there
may still be a form of motion parallax information, but it will be motion parallax due to movement of the camera rather than movement of the observer. So, for example, a driver might be able to get information about the distances of vehicles ahead on the road by moving his or her head from side to side. If the same driver was looking at a display that was linked to a camera mounted in a fixed location on the vehicle, the driver would still be able to get motion parallax information, but it would have to come from moving the vehicle (and camera) from side to side rather than moving the driver’s head within the vehicle.

**Visual Limitations**

Besides being able to process efficiently pictorial and nonpictorial visual cues, drivers must face another challenge. Visual perception is extremely limited by the quantity of information captured at one time.
Figure 14. Visual representation of binocular vision, emphasizing perimetal and foveal fields of view. (Hershman, 1997)

The binocular field of vision, as represented on Figure 14, can accommodate approximately 180 degrees horizontally and 135 degrees vertically. Despite its magnitude, only a small portion of the entire field of vision is capable of capturing high amounts of information from the visual stimuli.

"The fovea is less than .5mm (less than 500micrometers) in diameter, which means that maximum visual acuity occurs in less than 2 degrees of the visual field. Outside the
foveal area, the visual acuity becomes progressively poorer, decreasing than ten fold as the periphery is approached.” (Guyton and Hall, 1996).

The image focused on the central 6.2 degrees of the fovea – depicted as the red area in Figure 14 – are perceived in high definition.

Drivers are more likely to perceive elements that are positioned closer to the fovea.

“Acuity in peripheral vision. For daylight conditions, visual acuity diminishes rapidly with distance from the fovea as shown by data from Blackwell and McFadzean (1958) and Taylor (1961). This means that for a near-threshold target to be seen, the eyes must be fixated within an angle as small as 1°. At progressively greater peripheral angles, the target size must be increased to see the critical details. Using the data of Taylor, for example, a target at double the threshold size (relative acuity 0.5) should be visible at an angular displacement of about 4° or less from the fovea. (...) To be perceived by peripheral vision, the target must be several times larger than it has to be when seen by foveal vision” (Van Cott et al, 1972)

The peripheral area of vision is low resolution, but functions as a powerful radar for stimuli that should be further scrutinized by the foveal field of vision.
The importance of right and left areas of driving view is unquestionable. While most of the time the driver’s vision is directed straight ahead.

“Many accident-producing events are likely to first appear in the peripheral areas of his or her visual field, or even outside of the visual field”. (Shinar, 1978).

In order to perceive the information presented through the windshield, the driver’s eye move in a fast pace, focusing the foveal area in different focal, utilizing the saccadic movements.

“When the vision scene is moving continuously before the eyes, such as when a person is driving a car, the eyes fix on one highlight after another in the visual field, jumping from one to the next at a rate of two to three jumps per second. The jumps are called saccades, and the movements are called optocinetic movement. The saccades occur so rapidly that not more than 10% of the total time is spent in moving the eyes, with 90%
of the time being allocated to the fixation sites.” (Guyton and Hall, 1996).

In stress situations drivers are known to present less saccadic movements (Harbluk, 2002), leading to a higher rate of missed stimuli on the peripheral field of vision.

Attention

The human perceptual system is limited. To be able to cope with this plethora of stimuli that is presented through the windshield, the driver’s perceptual system has to be selective.

“This selective property of perception has long been designated by the term attention” (Dember and Warm, 1979).

“Driver inattention is a major contributor to highway crashes. The National Highway Traffic Safety Administration estimates that at least 25% of police-reported crashes involve some form of driver inattention. Driver distraction is one form of inattention and is a factor in over half of these crashes. Distraction occurs when a driver “is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object, or person within or outside the vehicle compels or induces the driver’s shifting attention away from the driving task.” The presence of a triggering event distinguishes a distracted driver from one who is simply inattentive or “lost in thought.” (Stutts et al, 2001)

Drivers’ ability to perceive and process information from both the environment and the system will play a major role on how well they will be able to respond accordingly to its demands by controlling the vehicle.

“The limit on the rate in which we can process information makes the role of attentional and visual search mechanisms extremely important. Those situations or events to which we do not attend are forever lost to our consciousness and, perhaps more important for driving, never responded to.” (Shinar, 1978).
After the information has been perceived, the rate in which it can be processed by the driver to generate appropriate responses will play a major role on this interaction cycle. The cognitive processes related to event evaluation and action selection will define the driver’s response.

Figure 16. The span of attention and the span of perception. (Dember and Warm, 1978)

Figure 16 illustrates the limitations on attentional systems – described analogously as a flashlight. Stimuli located in the focus of attention are more clearly perceived.

"Perception is a broad field, and different scientists interpret its definition in various ways. Moray (1969) built a theoretical model related to the attentive phenomena. This model describes the phenomena dividing it in 6 different distinctive subdivisions. (1) Selective attention is related to the limited capacity of the human perceptual system to perceive information. The attempt to exclude stimuli that may affect the task performance is described as (2) concentration. During (3) search, the individual scans through a set of signals in order to find specific information. Readiness to deal with whatever stimuli presented is defined as (4) activation. (5) Set - is the preparation to respond in a certain way or to receive a particular type of stimulus. Finally, vigilance, or (6) sustained attention is related to the ability to maintain attention for prolonged periods of time." (Dombes and Warm, 1978)

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The next two chapters will deal with the problem of how drivers select which information will be processed when they are presented with more than they can deal with; the second deals with drivers' efforts to sustain attention to infrequent but important events over extended periods of time.

**Select Information**

What makes the driver look one way instead of the other? A major distinction that has guided research in this area describes two main controllers of attention. As described in Pashler (Yantis – Control of Visual Attention, 1998) attention, or how we select information visually, can be defined as “top down” process when it is goal-driven, or stimulus-driven, controlled in a “bottom-up” fashion.

Visual attention is said to be goal-driven when it is controlled by the observer’s deliberate strategies and intentions. For example, when a driver is traveling through a highway looking for a particular exit ramp. The roadway signage, mostly the ones in yellow are more likely to be selected for further processing. On the other hand, other elements such as vehicles, billboards, and lane signage will be maintained on peripheral processing.

Attention is said to be “stimulus-driven” when it is controlled by a combination of two broad stimulus properties.

“One of these relates to the physical characteristics of the stimuli. (…) In general, several studies have shown that size, intensity and motion are important determinants of
attention, with the advantage going to large, bright and/or moving stimuli” (Woodworth and Schlosberg, 1954).

The second, but not less important is related to the “collative characteristics of the stimuli. These are properties which depend on comparison or collation of stimulus elements, and they are best described by such words as novelty, surprisingness, incongruity and complexity. (...) These studies revealed that novel and incongruous objects are almost always selected or fixated in preference to others.” (Dember and Warm, 1979).

For example, when a driver is traveling down the highway at nighttime, and there is a police car stopped at the shoulder ahead of him, it is unlikely that he/she will not focus his visual attention towards the blinking lights.

Although there is a patent theoretical distinction between stimulus and goal-driven attention, it is important to note that “any given act of attention typically involves some combination of the two attentional modes” (Posner or Yantis 1998). This shows that attentional control results from an interaction between the observer’s goals and the characteristics of the stimulus.

**Sustain Attention**

After information is selected to be processed, another problem has to be faced by the driver. Driving task will be affected by the driver’s inability to maintain the focus of attention over extended periods of time.
Figure 17. The decrement function in vigilance obtained during one of Mackworth's early experiments. (Dember and Warm 1979)

Figure 17 shows an experiment where subjects were asked to report stimuli presented on a display. The average incidence of missed stimuli increases from 15% to 30% in less than two hours. Considering that the average North-American spends from 45 to 90 minutes on a daily commute, we can assume that by the time he/she arrives at the destination, 25% or more of relevant information is being missed.

Decision-making

As we have discussed before, the immediate environment that surrounds the vehicle imposes multiple simultaneous demands on the operator. A number of these demands are measurable tasks, as when a driver scans outside traffic while navigate by human-
or machine generated – directions, or when he or she steers the wheel in order to maintain the vehicle inside the driving lane.

"Other activities are covert – planning, problem solving or decision-making, for example – but may be just as demanding of the operator's limited attention resources as are the more observable activities. As a result, they will be just as likely to interfere with other overt and covert activities." (Stokes et al, 1990)

Perceiving the relevant information alone does not guarantee that the driver will respond accordingly.

"Cognitive attention is another attention demand. The driver may be concentrating on one thing while his/her eyes are directed toward something totally unrelated (Cohen, 1971)" (ATIS/CVO Human Factors).

![Figure 18. Overall distribution of driver attention status based on the weighted 1995 – 1999 CDS data (Skaters et al, 2001)](image-url)
A study from NASS Crashworthiness Data System data, illustrated here in Figure 18, highlights that at least 5% of the drivers “looked but didn’t see” the stimuli right ahead of them. That is most likely because their cognitive attention was directed towards something else. Processing the information that is being perceived is a key factor to be able to respond to it appropriately. Cognition is a main factor regarding automotive environment, as the ability of the driver to control the vehicle depends on his/her ability to perceive stimuli (and respond to it), and how the driver processes stimuli is crucial.

The driver’s ability to process information is directly related to the amount of information he/she has to deal with at a time. When performing two or more tasks, different mental activities must be carried out, and performance will be affected.

Multitasking

The driver has been pushed towards a more complex environment, where in-vehicle systems present a wider variety of stimuli and multitasking is inevitable. Human interaction may be affected if they have to deal with more than one task simultaneously.

“As Hoentz, Haller and Boais (1982) pointed out, observation of (and control, response to) instrument panel displays in car is always a secondary task, and instrumentation must be evaluated for the degree to which it may distract from the primary task, the stabilization, control and navigation of the car.” (Stokes et al, 1990, pp. 5)

When dealing with two or more tasks at the same time, performance is likely to decrease. In the automotive environments, that is almost always true. The reduction is
related to increases on workload and decrease on available resources to deal with those problems.

"Two distinct modes of allocating attention to the perceptual world can be identified: a serial mode and a parallel mode. (...) Certain environmental conditions force subjects to operate in a serial processing mode. For example, in the automobile, scanning between the dashboard and the roadway outside forces a serial processing mode. (...) Indeed, most visual scanning tasks require the serial mode" (Stokes et al, 1990)

"Studies by Brown and his associates conducted in England (cf. Brown, 1963) demonstrated that under conditions requiring low attentional demands (e.g., light traffic) drivers were able to perform additional mental tasks without any impairment in the primary driving task. However, when conditions became stressful then deterioration was observed in either the primary driving task or the additional mental task." (Shinar, 1978)

**Mental Workload**

Mental workload is related to the degree of problem solving required by one particular task. Two major variables that affect the ability to time-share or perform multiple tasks concurrently: their difficulty and their structure.
Figure 19 shows a chart comparing two distinctive tasks, with Performance as a function of Resources. As the amount of resources increase, performance also increases. Task A requires more resources than task B. With the same amount of resources, task B (represented by the dotted line) reaches a higher level of performance, and is more automatic. Task B could be described as walking, for example. Most subjects would be able to walk without imposing higher levels of cognitive processing to it, or without dedicating a great amount of resources. Task A, on the other hand, requires more concentration from the subject in order to be carried out. It could be illustrated as driving, and entering a highway and observing the speed and position of traffic.
Resources

While the searchlight metaphor emphasizes the unity of attention, the resource metaphor emphasizes its divisibility and limitation.

"When performing any task, different mental operations must be carried out (responding, rehearsing, perceiving, etc.), and performance of each requires some degree of the operator's limited processing resources." (Wickens, 1992)

![Diagram](image)

**Figure 20.** Relationship between resources demanded by a task (X axis), resources supplied (solid line) and performance (dotted line). (Seokes, 1990)

**Figure 20** illustrates the relationship between resources demanded and resources supplied. Because resources are limited, some tasks will require more resources than the total available. When the resources demanded by a task are not sufficient to perform a task, the quality of performance will drop.

"Two activities will demand more resources than a single activity, and so there will be greater deficiency between supply and demand" (Wickens, 1992).
Response Selection and Execution

The information processed and the correct response is vital to complete the tasks and achieve the final goal of going from one point to another. As discussed before, accidents can occur as a failure of recognizing relevant cues from the environment, as well as the inability to process correctly the information that is being perceived, or inability of the drivers to select the correct response to a problem presented by the environment. Even when the relevant information is perceived and correctly analyzed, drivers can fail to select and execute a correct response, and accidents can occur.

These failures in selecting the appropriate response can be explain by one or more of the following phenomena: (1) Absence of a matching code on the driver's memory system, (2) existence of a matching but irretrievable code, (3) existence of a retrievable matching code that can't be matched or (4) lack of time to retrieve the matching code.

Problems may take place when the correct response is not available, or when it is stored, but is not accessible. It means that whatever stimulus the driver is exposed to either doesn't match a memory code that triggers a response, or it triggers a wrong response. One simple example is the traffic light. If it is red, the desired response is to step on the brakes and stop the vehicle. The information of red color equals stopping is the adequate response. This response has to be stored on the driver's memory system, and has to be available at the time he/she sees the light. Another example is a driver going through a street at 60 km/h. When the car is 15 meters away from the traffic light it turns yellow. To decide on whether he/she should brake, the driver has to calculate if
the space between the car and the traffic light is enough to come to a complete stop and if the car behind will be able to brake as well.

These are decisions that rely on LTM and STM, based on accessibility and availability of corresponding responses. The time available to make those choices will affect deeply the performance during the process of response selection. Previous research described a time-based model in which Hollnagel explains Response Selection based on time. Drivers evaluate their inputs through feedback and feedforward. Their ability to select correct responses will also be a function of the time necessary to make the selection and the time available to perform it.

On the model developed, Hollnagel states that “this functional approach is driven by the requisite variety of human performance rather than by hypothetical conceptual constructs (process genotypes). The observed regularities of human behavior by definition only exist in a given context, and actions occur in anticipation of events as well as in response to them” (Hollnagel 2002).

Artifact

“In the early days, the measuring instrument was an expensive option that only a few vehicle owners installed. It was not until 1910 that automobile manufacturers such as Ford Motor Co. began to include the speedometer as standard equipment. But the First World War and the world economic depression of the 1930s kept production down. Nevertheless, there were major advances. By the mid-1930s, an instrument cluster attached to the steering column grouped all the important gauges and indicators together, including those for engine revs, fuel, lights and turn signals. Although integration at that time was limited to a common mounting plate for separate scales and dials – a bracket really – it nevertheless was the first step towards combining several different instruments into a single instrument cluster.” (Siemens, 2002)

As technology evolved, different display techniques and methods emerged, but the necessity to present information to the driver remained.
Modern in-vehicle artifacts are composed by a variety of sensors, CPUs, screen displays, and other hardware and software apparatus that are able to collect, analyze and display information to the driver in a variety of modes. Among the artifacts that present information visually, three main technologies are available today on the automotive scene: Head-down Displays, Helmet-mounted Displays and Head-up Displays. To be able to design efficiently to this media, it is imperative to understand their current usage, the overview of the technology, and the positive and negative characteristics of the cited display artifacts.
Head-Down Displays

![BMW's dashboard-mounted HDD](http://www.bmw.com)

**Figure 21.** BMW's dashboard-mounted HDD. (http://www.bmw.com)

Head Down Displays consist of the set of instruments inserted on the vehicle console. Due to technological limitations, it was the first form of presenting information to the driver.

The vast majority of the automobiles today still rely on this class of hardware to exchange information between the vehicle, the environment and the driver. Despite the fast technological advances during the past few years, few display/visual communication design changes were made to the instrument gauge. Adopting a
language from the early instrumental gauge hardware, most of them utilize needles that rotate in a round numerical scale to display quantitative information. Most of them organize information and prioritize real estate related to importance. Speed is usually the predominant visual element, taking up most of the visual space, sometimes accompanied by the tachometer with similar importance.

Even today, with new technology, the visual communication design language is still the same. In most of the cases, to display quantitative information, a needle rotates and points to a round numerical scale. This was a technical limitation in the past. Although some "fully digital" displays were used, applying different methods of quantitative representation, the indicator dials are still number one.

![Image]

**Figure 22.** Fixed-Scale moving pointer, digital. (Simula, ID Magazine)

Head-down Displays are the most cost-effective method to present information to the driver. Another positive aspect of HDDs is the fact that drivers have to lower their heads to check information on the dashboard functions as a reminder that they have to look back to the road - their main source of information.
“Dashboard or panel-mounted displays offer powerful cues to switch attention that are not present with HUDs: the need to look up, change focus and change convergence” (Bosi et al., 1996).

Among the technologies available, the dashboard-mounted instrumentation is the one with lowest background variance. Light, color and textures conditions remain constant, simplifying the requirements for design elements by eliminating the need to adapt to different situations.

Because drivers have to look down in order to see the information presented by this type of artifacts, his/her ability to control the car according to the information that comes from the environment decreases momentarily.

“Research has shown that that deviation from the roadway lane center increases with longer eye-off-the-road time” (Zwahlen and DeBald, 1986) (ATIS/CVO Human Factors).

Another negative aspect of HDDs is that time to switch from the information on the dashboard to the environment displayed on the windshield and accommodate the focal point might take one second or more. This time to accommodate increases with population age.

**Helmet-mounted Display**

Helmet Mounted displays was first developed for military aircraft use. Robustness and flexibility of this type of artifact made it an ideal tool for visual search and targeting. Recently, Formula 1 team BMW/Williams started testing and using a prototype of Helmet Mounted display.
Figure 23. BMW/Williams' Formula 1 Racing Team Helmet-mounted Display prototype. (http://www.bmw.com)

BMW Technology Office announced recently that they integrated a Helmet-mounted Display (60nm x 8mm) into one of the pilot's helmet. This "visual information window" will allow a wide range of information to be relayed to the driver. The sample photo shows that there is oil on the track and precisely where and what to do to miss it. This mini HMD is an active matrix liquid crystal display (AMLCD) with a free from prism (FFP) to enable the driver to see the sharp image that looks to be out in front him. The HUD was developed in the BMW Palo Alto, CA facility.
Despite its use of Helmet Mounted Displays on aircrafts and F1 racing cars, its cost is prohibitive for commercial use. Also, besides restricting the driver’s field of view, it might not be comfortable to use a helmet with its hardware paraphernalia on a daily basis.

**HUD: Technology and Theory**

As its name indicates, the Head-up Display is a “hardware and software artifact that displays information at the operator or driver’s line of sight, and does not require the driver to lower the head or eyes to the instrument panel.” (Shinar, 1978)

![Figure 24. 1989 Oldsmobile Head-up Display. (Stokes, 1990)](image)
Head-up displays have been used in the aviation environment for many years, and more recently in commercial vehicles, to display critical information in the operator or driver’s line of sight, superimposed on the real-world scene.

“The HUD can use one of several projection sources to project an image (e.g., mi/h, warning indicators, etc.) onto the windshield. This information appears to be floating in space in front of the vehicle. The HUD allows drivers to keep their eyes forward, without glancing at the dashboard. HUDs have been successfully used in aircraft by giving the pilot a “window” to fly through. An automotive HUD is different from an aviation HUD in that the scenery behind the display is more complex for the driver than for the pilot. A second difference is that automotive HUDs are displayed not at optical infinity, as in aircraft, but at a closer distance, somewhat between 1.8 and 7.3 m (6 and 24 ft).” (Stokes et al, 1996).
Figure 25. Schematic view of a Head-up Display. Information is presented at the driver's line of sight. The light reflects on a collimator and is perceived as being projected outside the vehicle.

"The vast majority of HUDs display qualitative, quantitative, or representational information in digital, symbol or text format (e.g., vehicle speed, confirmation of indicators and alerting messages). The HUD images are collimated, or presented at a distance that is optically equivalent to the objects being viewed outside the vehicle." (Stokes, Wickens and Kite, 1990) (Bossi et al., 1996)

One of the most significant advantages of HUDs is that while using it, drivers are more likely to detect relevant events from the roadside, as their eye fixations are closer to these events. With the HUD, also, "information is presented in line with the driver's gaze on the windshield, but focused at infinity so that no ocular accommodation is required."
Shinar, 1978). Drivers are more likely to avoid lateral deviation as they maintain their eyes focused on the environment and are able to perform path corrections on the steering wheel faster.

Because drivers have to constantly evaluate the environment, HUD design elements should not obscure relevant events. Events that are not perceived by the driver might constitute a great threat and lead to accidents. Another significant problem associated with the use of HUDs may be their "potential for distracting the driver from paying adequate attention to the real scene. Although HUDs were designed to facilitate rapid switching of attention between instrument information and outside world (Dudfield, 1988; Sojournet & Ansin, 1990; Weintraub & Ensling, 1992; Weintraub, Haines & Randle, 1984), the proximity of information from both sources may actually interfere with that process." (Bossi et al, 1996)

Problems associated with the ever-changing background will impose a complex task to the design of Head-up Displays. Background changes in luminance, color, glare, and motion can mask or prevent the driver from perceiving the information on the windshield.
CHAPTER 4

ANSWERS FROM DESIGN

The improvements presented in this section are based on the limitations found throughout this research. A model will be presented exclusively to illustrate classes of solutions that can be presented based on the methodology discussed in this document.

The following design solutions are exemplifications of strategies on how to apply visual communication elements into HUD design. They have as a guiding principle the intent to overcome limitations from drivers, environments and artifacts. Their ultimate objective is to enhance driver’s ability to control the vehicle, by helping them perceive relevant information from the environment, understand the impact of those elements on the driving task, and select the appropriate responses.

Classes of design solutions

57
Select relevant information from the environment
Enhance perception
Demand fewer resources
Perceive and evaluate feedback
Avoid distraction
Focus on the primary source of information
Visualize information in different conditions

Table 2. Classes of solutions presented as examples, designed to aid drivers on specific areas.

Although the examples are described as distinctive solutions, there are two design principles that they should follow in order to achieve their objectives.

"First, the Gestalt principles of proximity or the information principles of display organization, redundancy, and symmetry, must be used to produce groupings or emergent features in the first place. Second, the organization formed by the spatial proximity of different elements on the display panel must be compatible with the cognitive organization of the task." (Wickens, 1995)

Select relevant information from the environment

This solution was designed to illustrate one example of how to help drivers select relevant information from the environment.
Figure 26. HUD alerts the driver for possible threat. (Adapted from freefoto.com)

A situation where a car is backing up, entering the path of another car is illustrated in Figure 26. The driver’s visual attention can be focused on a spot on the left hand corner, while he/she is performing a visual scan to find a spot to park. Collision avoiding systems can identify the threat and display visual elements that can be perceived through peripheral. The use of bright, moving or large elements can highlight the event and are most likely to call driver’s attention to the possible threat.
Enhance perception

Human vision perception is limited to certain levels of luminance, chrominance, and the disposition of objects in the field of view. Automotive Head-up Displays visual elements can be designed to help drivers perceive information beyond their senses' boundaries.

Figure 27. Lane markings are projected with HUD to assist drivers in conditions of low visibility. (ITS Institute – University of Minnesota)

Figure 27 illustrates the HUD developed by the Intelligent Transportation System Institute at the University of Minnesota. This artifact makes use of GPS and radio systems to pinpoint the truck’s location on the highway and present relevant information to the driver and assist in the task of driving under low-visibility conditions. When the driver is unable to see the snow-covered road, virtual lane markings are projected on the windshield/collimator via HUD.
Demand fewer resources

Different methods of displaying information can result in less or more effort from the driver in order to understand it. While visualizing a two-dimensional map, drivers have to interpret the information and translate it into the three-dimensional world to be able to come up with an adequate response.

Figure 28. Lane markings are projected with HUD to assist drivers in conditions of low visibility. (ITS Institute - University of Minnesota). (Siemens VDO)
Figure 28 shows an example of how to simplify displayed information in order to require less processing and resources from the driver. This prototype from Siemens VDO highlights the path that the driver has to navigate through, so that the he/she doesn’t need to use a large amount of resources trying to decode the information to transform it into a tangible response.

Perceive and evaluate feedback

In order to be able to know if they are performing adequate actions, drivers have to be able to evaluate the feedback from the environment. When the cues are not available, or are not sufficiently evident, automated systems can trigger and display visual elements on the windshield to alert the driver.
Figure 29. A visual element alerts the driver when he/she is unintentionally deviating from the lane and should align the vehicle to his/her lane. (Adapted from AAA Foundation for Traffic Safety)

Figure 29 illustrates a visual stimulus alerting the driver for the threat of deviating to the lane on the right. By visualizing the design element, the driver can make the corrections necessary and maintain control of the vehicle.

Avoid distraction

The artifact should not distract the driver from relevant events that may occur.
Figure 30. Visual element can deviate driver's attention from relevant information. (Adapted from AAA Foundation for Traffic Safety)

Figure 30 exemplifies a situation where a visual element is displayed on the right hand corner while a car is entering the vehicle path on the left hand corner. In this case, drivers might tend to look at the HUD visual element and miss the incoming vehicle. To avoid this class of problem, content and timing of information presented on the windshield should be defined through automated systems. Also, the format in which the stimuli is presented should be defined through Visual Communication Design principles.
Focus on the primary source of information

Figure 31. A Head-up Display visual element may obscure incoming traffic. (Adapted from AAA Foundation for Traffic Safety)

Probably the most important feature from all Head Up Displays is to be able to convey information without obscuring important cues from the environment. Because most of the information that the driver relies on to control the vehicle is visual, and comes through the windshield, the major goal should be to make these cues more visible. Use areas right above hood for certain class of information. Possible alternatives to avoid this problem are to use levels of transparency to show what’s on the background and circumvent high information visual areas on the windshield.
Visualize information in different conditions

The environment seen from the windshield is constantly changing, and so are the actions that the driver has to take to control the vehicle. Differences in brightness, (from day to night, or while passing through a tunnel), hue values (from different seasons, different objects), and contrast (rain, fog, sun, snow), are always changing. The information displayed on the HUD also has to change, adapting to each situation.

Figures 32 (left) and 33 (right), Visual elements with same hue values can be quickly identified under summer conditions, but not under snowy weather. (Adapted from AAA Foundation for Traffic Safety)

The example illustrated in Figures 32 and 33 show the comparison between the same design elements displayed in two different conditions. In “summer” conditions the projected stimuli can be clearly visualized and identified. When presented in a different weather condition, the snow in the background has a similar hue value and masks the visual design element. In this case, information might be unnoticed by the driver. Information displayed on the windshield should change according to the hue values of the background environment, and adjust in order to make it noticeable to the driver.
Figures 34 (left) and 35 (right). Visual elements with same luminance values are difficult to be perceived during daytime, but quickly identified at night. (Adapted from Scialfa, 1999)

Differences in lighting conditions will also affect the driver’s ability to visualize the information. Figure 34 shows visual elements projected on the background during daytime, while Figure 35 presents the same stimuli on night condition. Similar luminance values can prevent drivers from perceiving the information. Analogous to hue values, brightness and contrast values should adapt to the environment, generating a sufficient amount of contrast to be perceived by drivers.
CHAPTER 5

TESTING EFFECTIVENESS OF IN-VEHICLE DISPLAYS

Testing the effectiveness of a system is important. Through testing designers can determine whether the artifact is useful and usable by the intended audience. In the automotive environment, the artifact’s usability and the quality of the interaction will have a direct impact on the driving quality – and safety. The question that remains is when to test, and how to do it.

As suggested by Wickens, 1992, on an iterative design methodology, testing should be applied since the early stages of design. This approach facilitates locating pitfalls and correcting them early, and reducing costs.
Different methods were developed up to today. As illustrated on Figure 36, input from individual and collective limitations of drivers, artifacts and environment are considered during the early stages of design. After tested, the results can be compared to the desired results. If the testing results do not reach benchmark level they should be redesigned and the problems corrected. That process is in loop until benchmark results are achieved and the product is released. From empirical to analytical methods, each one of the approaches will be more successful in elucidating different questions about different systems.

The most widely employed method today is the “SAE Recommended Practice J2364, commonly known as the 15-Second Rule for Total Task Time or the 15-Second Rule, specifies the maximum time allowed (15 seconds) for completing a navigation system task involving manual controls and visual displays when the task is performed statically. The scope of the rule (Society of Automotive Engineers, 2000) reads as
follows:

“This Recommended Practice applies to both Original Equipment Manufacturer and aftermarket route-guidance and navigation system functions for passenger vehicles. It establishes a design limit for the total task time for the presentation of visual information and the manual control inputs associated with navigation functions accessible by the driver while the vehicle is in motion. The Recommended Practice does not apply to voice-activated controls or to passenger operation.” Section 4 (function accessibility criteria) states, “Any navigation function that is accessible by the driver while a vehicle is in motion shall have a static total task time of less than 15 seconds.”

SAE research affirms that for testing in-vehicle artifacts, the 15 seconds rule is effective. It states that any artifact that requires less than 15 seconds from the user to achieve his/her goal is acceptable—it is tested while the vehicle is not in motion. For this research we want to state that testing the interface alone is not enough, and that we are interested in the impact that it has on the driving quality, or the ability of the driver to control the vehicle.

The use of human subjects to test is usually a form of locating most of the features that can be improved on interactive media. They often require more time and resources to be performed. Different methods that consist of inquiring experts to analyze a product on an organized fashion can be used to efficiently identify most common problems, in a more time-cost-effective way.

When related to driving, empirical methods are especially difficult to be utilized, but extremely elucidating. Analyzing driver’s behavior imposes the difficult task of reproducing the driving environment for practical purposes. The risks of accidents implied in using subjects interacting with actual artifacts while controlling a car—even
on closed tracks - are too great. The use of simulators to replicate the driving conditions is a tangible alternative, but up to this date still presents some shortcomings. Although it seems that by isolating some of the variables during testing some salient findings can be made, it is usually the collection of them altogether that makes that environment a unique experience.

Despite the infinite amount of performance levels that can be measured to evaluate positive or negative impacts of artifacts on the driver performance, two of them seem to have a greater effect on the driver-vehicle-environment system: The first one is related to how much the artifact affects the driver's internal mental processes, interfering with his/her ability to select correct responses to the problems presented during the driving task. The second one is associated with the artifact's impact on the driver's external behavioral processes, or his/her ability to successfully control the vehicle.

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**Table 3. Selection of testing methods for in-vehicle artifacts**
Eye Tracking

This technique provides valuable insight related to driver's visual behavior while interacting with an in-vehicle artifact. Information about where drivers eye fixations can be used to verify if the artifact design is likely to help the driver to control the vehicle.

Figure 37. Subject wearing eye tracking system. (Harbluk, 2002)

Assessment on whether or not the driver is focusing on relevant information from the environment is imperative in order to evaluate the efficiency of the artifact design.
Information related to the duration of driver's eye fixations on HUD visual elements can provide data about driver's difficulty in recognizing them. Also, information collected by the eye-tracking device, in combination with data from different workload assessment techniques can provide a solid framework to understand the mental processes that are taking place during interaction.

NASA TLX

TLX method is a multi-dimensional flight-relevant subjective workload technique is the multi-attribute rating scale developed by Hart and her colleagues at NASA Ames Research Center.
This approach is composed by a scale used by subjects to evaluate and "rate imposed task demands in terms of physical, temporal and mental characteristics, and subjective experience in terms of effort, success-failure and frustration." (Stokes, 1990)

NASA TLX method is uncomplicated and can provide a solid and standardized scaffold to evaluate in-vehicle artifact and it's impact on driver's behavior.

Driving performance can be measured by using two main elements as parameters: lateral deviation and braking reaction time. (Lee, 2000)

**Brake reaction time**

Drivers' breaking behavior plays a major role on vehicle control. The ability to brake whenever required is a key factor to avoid accidents.

"Previous research (...) suggested that drivers would demonstrate more incidents of hard braking when they were distracted than when they were not" (Harbluk, 2002).
**Figure 39.** Brake reaction time is measured by time taken for a driver to respond and activate brakes.

As illustrated in **Figure 39,** brake reaction time is measured from the time a stimulus is presented and the brakes are activated. Better driving performance is reflected by low brake reaction times.

**Lateral deviation**

Besides the ability to effectively be in command of vehicle’s speed and stop it when necessary, drivers have to be able to maintain lateral control at all times. Along with brake reaction time, assessing lateral deviation is a simple but effective way of measuring if the artifact is having a positive or negative impact on the driving task.
Figure 40. Lateral deviation is measured through differences in distances between the vehicle and the lane markings.

Figure 40 illustrates a schematic view of lateral deviation measurement technique. While driving the vehicle and interacting with the artifact, distances between the automobile’s wheels and lane markings are measured. Better driving performances will have two characteristics. The first one is the comparison between distance from the right wheel and lane markings (A) – and left wheel and lane markings (B). The closer values between (A) and (B) are closer to better driving performances. The second characteristic is analyzed based on variations on distances for each individual side. Greater values represent poorer driving performances.
CHAPTER 6

CONCLUSION AND FURTHER STEPS

The path to design efficient in-vehicle display interfaces should not rely solely on automakers’ marketing research that can identify users’ buying needs. Designing interfaces focused on utilizing the full potential of available technology does not seem to lead to a successful product either. Collaboration between corporate and academic institutions should rise as the most significant approach to fully explore technology on behalf of users’ needs. The fabrication of efficient artifacts should also rely on the integration of different disciplines and include areas of knowledge such as Design, Marketing, Cognitive Engineering, and Psychology.

The fusion of such disciplines can only add to the quality of in-vehicle artifacts, while it demonstrates that the use of appropriate design elements, along with the use of an extensively automated system would be the key to overcome driver, artifact and environment’s limitations.
Besides answering problems that are specific to the design of in-vehicle artifacts, this research also provides grounds for improving the interaction design discipline as a whole. First, by highlighting the need to design interfaces that are easier to use, and more useful for a broader audience. Second, by showing that in order to increase both usability and usefulness of an interface, designers should encompass a more profound knowledge about (1) users’ physiological and psychological capabilities and limitations to perceive, process and respond to presented information, (2) computational hardware and software systems technical constrains and (3) characteristics of the environment where users and computational systems are inserted. Success of interaction design will also depend on information gathered related to the system composed by these three elements and the interactions between them, understanding how they influence and change each other.

This study achieved its initial objectives by proposing a design methodology that can be applied and tested, and by providing tangible illustrations based on the framework developed. With the intent of being more objective, this document isolated one perceptual channel and only incorporates discussions pertaining visual perception. In order to fully understand the interaction process and its impact on the design of effective artifacts, further research ought to be developed and different modalities should be integrated to the actual model.
The methodology presented on this study suggests that instead of providing pre-fabricated answers to existing problems, designers should better understand each problem individually and comprehend that the matrix composed by each participant of this equation is likely to produce an inimitable setting with unique interactions. These unique interactions will require an exclusive design solution in order to make the communication process more fluid, thus, more efficient and less noisy.

Finally, despite a designer’s ability to access and internalize a myriad of information related to users, computational machines and the environment where they are inserted, no interface will be as effective as it could if it is not tested.

Know your problem. Test your solution.
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