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Human Factors Design Guidance for Level 2 And Level 3 Automated Driving Concepts

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13. ABSTRACT

High automation presents the opportunity to increase the safety, mobility, and efficiency of the existing road network, and has been anticipated for decades. It was not, however, until the development of sophisticated sensing and computing systems that such vehicles became technically feasible. Many automakers and Tier-1 suppliers are developing or testing vehicles with some form of automation. In support of the motor vehicle automation effort, NHTSA is planning a automation driving system (ADS) research program in coordination with other USDOT agencies with the goal of improving motor vehicle safety. Driver vehicle interface (DVI) design guidance has been developed as part of a larger research effort intended to perform an initial human factors assessment of driver performance and behavior under Level 2 and Level 3 automated driving. Safe and efficient operation of any motor vehicle requires that the DVI be designed in a manner consistent with driver limitations, capabilities, and expectations. This document is intended to assist DVI developers achieve these outcomes.

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Chapter 1. Introduction

Background

Motor vehicle automation can potentially improve highway safety by supporting or supplementing the driver, thereby providing precise vehicle control during normal driving, and by maintaining appropriate driver attention to traffic and roadway conditions. Although it is expected that automated systems will not have universal capabilities in all traffic and environmental conditions for some time to come, applications in motor vehicles will likely include a driving experience of seamless transitions between automation and manual control of motion control system functions in complex and rapidly changing conditions.

Higher levels of driving automation systems present the opportunity to greatly increase the safety, mobility, and efficiency of the existing road network. Automated vehicles, however, have been "coming soon" since the first half of the 20th century, when vehicles guided automatically along a highway were described at the 1939 World's Fair (O'Toole, 2009). It was not until the development of sophisticated sensing and computing systems that such vehicles became technically feasible. Prior large-scale efforts, such as the Federal Highway Administration (FHWA) Automated Highway System (AHS) research, provided some information as to the potential of automated systems. Yet it was not until newer explorations of ground vehicle automation and highly-visible events such as the 2004 and 2005 Defense Advanced Research Projects Administration (DARPA) Grand Challenge that the near-term potential of vehicle automation became apparently to the broader community.

While some relevant research exists from AHS or adaptive cruise control (ACC) projects, current and near-term implementations of driving automation have not been extensively researched. Further, at the time of writing this document, a number of automakers and Tier-1 suppliers are currently developing or testing vehicles with some form of automation. Thus, constructing appropriate design guidance for automated driving requires, and must be partially based upon an, understanding the broader field of human factors in automation and human-automation interaction, as well as attempting to understand how automation is likely to be implemented in the near-future.

In support of the motor vehicle automation effort, the National Highway Traffic Safety Administration's Office of Crash Avoidance and Electronics Systems Safety Research is planning an automated systems research program in coordination with other USDOT agencies including the Research and Innovative Technology Administration (RITA),[1] FHWA, Federal Motor Carrier Safety Administration (FMCSA), and Federal Transit Administration (FTA). The goal of the program is to improve motor vehicle safety by defining the requirements for automation in driving that is: (1) functionally safe and electronically reliable; (2) operationally intuitive for

[1] The Research and Innovative Technology Administration (RITA) was moved by Congress in 2014 to the Office of the Assistant Secretary for Research and Technology (OST-R), a part of the Office of the Secretary of Transportation (OST), which is home to all the program offices and statistics and research activities previously administered by RITA.

drivers under diverse driving conditions; (3) compatible with driver abilities and expectations; (4) supportive of improving safety by reducing driver error; (5) operational only to the extent granted by the driver and always deferent to the driver; and, (6) secure from malicious external control and tampering. Addressing the human factors questions is central for accomplishing these goals.

A key element of vehicle automation is the driver-vehicle interface or DVI. The DVI refers to vehicular displays that present information to the driver, and controls that facilitate the driver's control of the vehicle as a whole as well as the status of various vehicle components and subsystems. Safe and efficient operation of any motor vehicle requires that the DVI be designed in a manner that is consistent with driver limitations, capabilities, and expectations. This document is intended to assist DVI developers to achieve these outcomes. This DVI design guidance has been developed as part of a larger research effort—Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts—that is intended to perform an initial human factors assessment of driver performance and behavior under Level 2 (L2) and Level 3 (L3) automated driving.

Overview of Automation

Uses of Automation

Automation has been defined as a device or system that accomplishes (partially or fully) a function that was previously or conceivably could be performed (partially or fully) by a human operator (Parasuraman, Sheridan, & Wickens, 2000). Historically, the use of automation has been found in process control and aviation but, today, examples of automation can be found as well in non-industrial and personal uses. Automation in vehicles has the potential to help drivers who choose to engage in distracting behaviors (e.g., text messaging while driving) or who are experiencing a high level of workload by filling the gap between the driving demands and the capabilities of the driver. While there are many automated systems in the vehicle (such as automated driver assistance systems or safety systems that intervene in the absence of driver responses to specific situations), for the purpose of this document automation is a system that physically performs a specific combination of driving functions for the driver (e.g., maintain headway and steer the vehicle in a lane during a traffic jam, choose and execute a route to a chosen destination, or park the vehicle).

Philosophies of Automation

In developing a system that will include some degree of automation, system planners and designers may begin by first determining which functions the automation will take over from the driver and which functions the driver will continue to perform. Research in human-automation interaction provides four general automation philosophies that provide a way to view, or in some cases determine, this allocation of functions between the human and the automation:

- The "left-over" or residual function principle is the earliest automation philosophy. Under this philosophy, the automation is designed to perform as many functions as possible, with the remaining functions being allocated to be performed by the human. The rationale behind this philosophy is that since the automation can be designed to perform functions or tasks more quickly, reliably, and with fewer errors than a human, it should perform as many of the tasks as possible. This philosophy proposes that only functions that can be automated completely and will not suddenly require the intervention and support of a human should be automated (Hollnagel & Bye, 2000).

- The compensatory principle, or "Fitts List" (Fitts, 1951), is a list or table of the strong and weak features of humans and machines used as a basis for assigning functions and responsibilities to the various system components. As shown in Table 1-1, the function that humans are better at are the functions that would be assigned to the human to perform and functions that machines are better at are those that would be assigned to the automation to perform. Under this automation philosophy, humans are seen as mainly responding to what happens around them and their actions are the result of processing input information using whatever knowledge they may have (i.e., their mental models; Hollnagel, 2004).

Table 1-1. Human and machine function allocation.

Humans are better at:	Machines are better at:
• Detecting small amounts of visual or acoustic energy • Perceiving patterns of light or sound • Improvising and using flexible procedures • Storing large amounts of information for long periods of time and recalling relevant facts at the appropriate time • Reasoning inductively • Exercising judgment	• Responding quickly to control signals and applying great force smoothly and precisely • Performing repetitive, routine tasks • Storing information briefly and then erasing it completely • Reasoning deductively, including computational ability • Handling highly complex operations, i.e., doing many different things at once

- Dynamic function allocation (as opposed to the static approaches above) is a complementary approach that enables the human and automation to trade off which functions each performs based on the current situation. Instead of focusing on what types of functions the automation is better at performing and what types of functions the human is better at performing, as seen with the Fitts List, the focus is now on how humans and the automation can complement and support each other to achieve the overall purpose (Grote, Weik, Wäfler, & Zölch, 1995; Wäfler, Grote, Windischer, & Ryser, 2003). This approach aims to sustain and strengthen the human's ability to perform efficiently by focusing on the work system in the long term, including how routines and practices may change because of learning and familiarization.

- Adaptive function allocation is an extension of the complementary approach which assumes criteria to determine whether functions must be reallocated, how and when based on changes in the operating environment, loads or demands to operators and performance of operators (Inagaki, 2003). An automation system that operates under an adaptive function allocation is called adaptive automation. Adaptive automation can be used to help regulate workload by having the operator control a process during periods of moderate workload and then hand-off control of particular tasks when workload either rises above or falls below an optimal level (Hilburn, Molloy, Wong, & Parasuraman, 1993; Parasuraman & Wickens, 2008). Adaptive automation can also assist in keeping the operator in-the-loop by altering the level of automation being used. This information should be used with caution, however, as frequent cycling between automated and manual control may sometimes, but not always, cause a decrease in performance.

Automation in Vehicles

NHTSA's *Preliminary Statement of Policy Concerning Automated Vehicles* (NHTSA, 2013) provided an initial taxonomy of road vehicle automation that included five levels of automation. Additionally, the *Statement of Policy* provided information on the developments in automated driving at the time and an overview of NHTSA's automated systems research program. The SAE also defined a taxonomy (SAE J3016, 2014) that consists of six levels of automation, which was adopted by NHTSA (described below in Table 1-2).

Table 1-2. Summary of SAE International driving automation levels.[2]

Level and Name	Description
Level 0 (L0) No Driving Automation	The human driver does all the driving.
Level 1 (L1) Driver Assistance	Vehicle is controlled by the driver, but some driving assist features may be included that can assist the human driver with either steering or braking/accelerating, but not both simultaneously.
Level 2 (L2) Partial Driving Automation	Vehicle has combined automated functions, like speed control and steering simultaneously, but the driver must remain engaged with the driving task and monitor the environment at all times.
Level 3 (L3) Conditional Driving Automation	An automated driving system on the vehicle can itself perform all aspects of the driving task under some circumstances. Driver is still a necessity, but is not required to monitor the environment when the system is engaged. The driver is expected to be takeover-ready to take control of the vehicle at all times with notice.
Level 4 (L4) High Driving Automation	The vehicle can perform all driving functions under certain conditions. A user may have the option to control the vehicle.
Level 5 (L5) Full Driving Automation	The vehicle can perform all driving functions under all conditions. The human occupants never need to be involved in the driving task.

The SAE International taxonomy is applicable to all implementations of driving automation, is technology agnostic, and has some important distinctions, assumptions, and implications. From these, functional distinctions and assumptions follow the associated role of the driver of the vehicle at each level.

L2 vehicles are interesting as they may, in some implementations, utilize existing production technologies, such as radar and machine vision technology, to provide robust automation. L3 vehicles may utilize these or a completely different set of technologies in support of automation.

[2] As technically defined in SAE J3016.

From the average driver's perspective, the actions of a highly-performing L2 system and any L3 system performing the same automated function may appear to be the same. The highway speed automation in L2 or L3 controls the system by keeping the vehicle within its lane and controlling the speed and headway to any leading vehicles. Ensuring the driver builds an appropriate mental model, the driver is provided with information about the status of the automation, and is aware of what the automation may or may not do while actively controlling the vehicle may yield significant benefits. Yet there is a lack of published research examining how drivers form mental models of different levels of vehicle automation, and how those mental models are applied (and especially how mental models are applied between different levels of vehicle automation). While research into driver performance with L2 and L3 systems is in a nascent stage, examining drivers' interactions with different levels of automation may provide highly useful information for DVI design guidance in such vehicles.

As the level of automation increases, the driving role shifts from the driver to the vehicle. Under L2 automation, drivers are expected to serve as a monitor of automation as they are ultimately trusted to ensure the safe operation of the vehicle. The SAE definition states that L2 automated driving systems can release control with little or no advance warning. At higher levels of automation, the vehicle starts assuming more aspects of the driving role while under automated control. In contrast to L2, under L3 automation drivers are not expected to monitor the environment when the system is engaged, but they are expected to be takeover-ready to take control of the vehicle at all times with notice. Therefore, the L2 driver is expected to be alert and monitoring the road continuously. The L3 driver is not expected to be paying attention to the road at all times, but is expected to be takeover-ready with advance notice.

This is a unique situation in terms of the driver's attention. The L2 driver has been relieved of the control level of driving task, and potentially some of the maneuvering level (Michon, 1985). Thus, the driver of the L2 vehicle has transitioned from the role of active driver to one of a monitor of driving automation. Under L2 automation, the driver is expected to monitor the road, the performance of the automation, and be ready to intervene if something functions incorrectly or if asked to do so. In contrast, the L3 driver has transferred control, maneuvering, and perhaps some of the strategic choices to the automation. The driver must be ready to resume control at any time with advance notice in L3 automation. The L3 driver, largely relieved of the role of driving, is not required to constantly monitor the vehicle or road status; the L3 driver is only asked to be ready to intervene if warned in advance.

Note that the L2 driver is engaged in the monitoring task even as event rate and workload are reduced to what may be described as a vigilance task (O'Hanlon & Kelley, 1977). While monotonous driving over time has been identified with poorer performance in both laboratory evaluations of driving and naturalistic evaluations of long-duration commercial vehicle driving (Thiffault & Bergeron, 2003; Soccolich et al., 2013), it is currently unknown how drivers will perform in terms of sustained attention under longer duration L2 or L3 automated driving. Related to this, emerging research suggests that drivers, when relieved of actively controlling the vehicle, may engage in a variety of non-driving tasks that can involve significant levels of distraction (Llaneras, Salinger, & Green, 2013). Taken together, the potential for a vigilance-like state and behaviors that would be termed distraction in manual driving provide the foundation for important guidance on L2 and L3 automation DVIs. Understanding lessons learned in how to provide both safety-critical and non-safety critical messages to operators who are either in a vigilance state or involved in secondary (divided attention) tasks provides useful information for the designer of L2 and L3 automated system DVIs. The implication for design guidance is that, under L2 and L3 operations, automation-specific messages (and especially safety-critical messages) may need to be provided in a distinctive and highly salient manner as the driver may not be currently monitoring the forward roadway (Llaneras et al., 2013). Further research in this area is likely to provide highly useful guidance and understanding best practices.

The definitions of L2 and L3 automated systems also have implications for the DVI in terms of transfer times. The L2 system driver is expected to be able to take control with little to no advance warning. The L3 system's driver is expected to be able to take control with a sufficient and comfortable transition time. The issue of advance-notice transfer time may be considered both in terms of the active status of the road (the origin of the take control message) and of the driver's status (e.g., engaged in another task for the last 10 minutes). Perhaps more critical from a DVI design standpoint is the "no advance warning situation" possible in L2 vehicles. L2 vehicles have the potential to fail in such a manner that no advance warning is provided (a "silent failure"). One such example of this would be that of a vehicle incorrectly following lane markings and (intentionally) drifting onto the shoulder instead of continuing on the road. In this hypothetical example, the inattentive driver would not be informed of this until the vehicle encountered the infrastructure-based warning of the rumble strip. The issues surrounding no advance warning transfers and how drivers sample the road in different levels of automated driving, as well as transition times for both L2 and L3 automated systems, remains largely unexplored. The need for research in this topic was acknowledged, however, and existing knowledge considered in the design principle generation process. Some of the applicable lessons learned from the broader human-automation interaction field are described in the following section.

General Design Issues for Automated Driving Systems

Due to the fact that automation has been used in a variety of domains, for decades in some cases, a large body of research exists regarding what can be considered basic design issues when developing automated systems. These issues are listed here.

- Trust in automation (Lee & Moray, 1994; Muir & Moray, 1996; Lee & See, 2004; Rajaonah, Anceaux, & Vienne, 2006)

  As vehicle automation is able to perform more functions for the driver, the driver's confidence in the automation's ability to perform these functions and a willingness to rely on information provided by the automated system becomes more important. For example, if the automation system alerts the driver to a hazard, even when the hazard is not immediately observable, the driver prepares to take the necessary action to prevent from hitting or running over the hazard. In terms of L3 automation, in which the driver can cede full control of all safety-related functions to the automation under certain traffic or environmental conditions, the topic of trust in automation is particularly relevant due to the fact that the automation is the primary source of ensuring safe operation of the vehicle.

- Misuse, disuse, and abuse of automation (Parasuraman & Riley, 1997)

  Using automation when it should not be used, ignoring or turning off automated alarms or safety systems due to reoccurring false alarms, or implementing automation without regard for the consequences for human performance can affect a driver's trust in the automation system. Proper design of the automation system and appropriately calibrated trust in the automation system may help support drivers' appropriate use of the automation. As higher levels of automation are implemented (L2 and L3), this is a particularly relevant topic because the consequences to safety are higher as the driver is less engaged in driving (in L2 automation) or is performing fewer safety-related functions (in L3 automation).

- The out-of-the-loop problem (Endsley & Kiris, 1994; Stanton & Young, 1998; Seppelt & Lee, 2007)

  If a driver is not provided with the proper information about the automation, and potentially road/traffic status, he or she may suffer from a diminished ability to detect automation failures and to re-claim manual control of the vehicle if necessary. This is a topic that is becoming more important as higher levels of automation (L2 and L3) are implemented in vehicles and drivers are potentially able to perform non-driving related tasks while in the vehicle. At these levels of automation, the automation is performing nearly all, if not all, of the primary driving tasks, meaning that a driver could be so involved in a non-driving related task (e.g., texting, checking e-mail, reading a book, etc.) that he or she could completely miss a warning or message from the automation, possibly leading to a crash or other incident.

- Failures in automation (Endsley & Kiris, 1994; Stanton & Young, 2000)

  As automation systems have been implemented in various domains—including in vehicles—the reliability of these systems has improved. Even with the most advanced automation available, however, the reliability will never be perfect. Performance after a failure may be better if the driver has a realistic understanding of the reliability of the system, and the types of system failures that could potentially occur. In a scenario in which the automation fails, there may be benefits if the driver could be alerted to the failure with plenty of time to re-claim manual control of the vehicle from the automation. As L2 and L3 automation are designed and implemented in vehicles, the status of the automation and being alerted to a failure of the automation system may become even more important due to the fact that a driver is unlikely to be in contact with either the steering wheel or the pedals. This means that the sooner he or she can tell that the automation has failed or is alerted to the fact that the automation as failed, the sooner he or she can prepare to and ultimately re-claim manual control of the vehicle.

- Workload and the implementation of automation (Young & Stanton, 1997)

  The implementation of automation is often expected to reduce driver workload, which during periods of high workload can be helpful. However, underload—resulting from fewer driving tasks—can also occur, potentially causing a driver to be become bored due to the lack of tasks to perform. The prevention of the driver becoming bored or fatigued due to underload is particularly relevant in terms of (primarily) L2 automation since the reduction of driver-performed functions is great to begin with. Therefore, L2 automation could be adaptive, meaning that there could be a balance between which functions the driver was still performing and which functions the automation was now performing, impacting the workload experienced by the driver.

- Clumsy automation (Wiener, 1989)

  If the automation is designed to perform the easier task for the driver, leaving him or her to perform the more challenging task, the result is clumsy automation. In terms of workload, with this type of automation, the automation reduces the workload experienced when it is already low and increases the workload experienced when it is already high. This topic is important because if automation makes the driving situation more challenging than it already is, it defeats the purpose of implementing automation. When designing L2 automation, designers and systems planners could consider adaptive automation to address this concern. As mentioned above, this may help keep the workload experienced by the driver balanced and will potentially reduce the occurrence of clumsy automation altogether.

- Mode awareness (Sarter & Woods, 1995)

  When a driver is using a level of automation and fails to detect a change in the level of automation, it is called a mode awareness failure, or automation surprise, e.g., when a driver engages a lane centering system and then, for an unknown reason, the lane centering system disengages. Without proper feedback, the driver may not know the lane centering system is disengaged and might not take the necessary steps to re-claim manual control of the vehicle and to correct or change the course of the vehicle. As the ability of the automation to perform functions for the driver increases, the potential for the driver to possibly engage in non-driving related activities also increases, making the process of alerting the driver to any critical changes in automation mode more important.

Current and Future Directions of Vehicle Automation

Available Technology

Currently, L1 automation technologies are available in some, but not all, new light vehicles on the market today and L2-type technologies are beginning to become available from different manufacturers (NHTSA, 2013). L1 automation technologies are designed to assume a portion of driving authority over a primary control (e.g., adaptive cruise control).

L2 technologies could allow the driver to physically (but not cognitively) disengage from the driving task and assume the role of monitoring the road and vehicle performance. Some L2 technologies, such as ACC plus lane centering, are also available in new light vehicles on the market.

L3 technologies allow the driver to cede both the monitoring and control role for the full driving task to the automation under certain conditions but expect the driver to be takeover-ready when the system may request it. An example of an L3 concept is traffic jam pilot, which allows drivers to engage the automation and cease monitoring the road. As L2 technologies allow the driver to physically disengage from the driving task, L3 technologies allow the driver to relegate full control of the driving task to the vehicle. These L3 technologies, while experiencing varying degrees of maturation while in development, are not currently available in the United States light vehicle market, yet they are expected to be available in the near future.

L4 and L5 technologies, which are expected to only require the driver to input a destination while the automation monitors the roadway and performs all safety-critical functions, do not yet exist outside of advanced research concepts. L4 systems are constrained in a domain, and L5 systems can operate without such limitations.

Role of the Driver

With the implementation of automation in the vehicle come changes in the role of the driver in the driving task. When performing the driving task manually (under L0 or L1 automation), the driver is actively participating in the task. The driver is completely responsible for control of the vehicle and monitoring the roadway for safe operation of the vehicle. When a level of automation is added, however, part of the task is taken over by the automation, leaving the driver to participate in less of an active manner and more of a passive manner during normal operating conditions. For example, under L1 automation the driver may still be responsible for steering the vehicle, but is not responsible for maintaining a safe following distance behind the vehicle in front of him or her when using ACC. Under L2 automation (extending the previous example to include both ACC and lane centering) the driver is expected to monitor the performance of the vehicle continuously, but the system may manage vehicle headway and lane position appropriately for extended period of time without intervention from the driver.

Increased automation and the accompanying shift to a role of automation monitor presents the potential for driver underload. Research from domains such as unmanned vehicles and control systems has suggested that increased time in a monitoring role can lead to reduced performance (Cummings, Mastracchio, Thornburg, & Mkrtchyan, 2013). It is unclear, however, whether this can be extended to driving. As automation technologies improve and evolve, the role of the driver in the driving task must be assessed and reassessed as changes continue.

Automation Transitions

As higher levels of automation are researched, designed, tested, and eventually implemented, additional design considerations will need to be discussed. A main concern with near-term and future levels of automation is the occurrence of planned and unplanned transitions between the levels of automation and the impact that these transitions will have on the timing of delivering information to the driver (e.g., much before the transition, near the occurrence of the transition), the modality of delivering the information to the driver (e.g., for the auditory modality, a single tone, a consistent tone, an auditory icon), and what specific information that will be communicated to the driver (e.g., what function the automation was performing but is not now, that the automation went from L3 to L1). To keep the driver in-the-loop as best as possible, enabling him or her to re-claim manual control of the vehicle more quickly if necessary, addressing the following questions may be of value: what information should drivers receive about the transition in level of automation, when should drivers be alerted about the transition between one level of automation and another level of automation, and how should drivers be informed about the transition in level of automation? This is a particularly important topic due to the fact that near-term in-vehicle automation (L2 and L3) will, at least in the beginning, likely consist of short cycles between the different levels of automation, meaning a short duration of time between engaging the automation and then returning to manual mode.

Short-cycles of automation can also be found in the aviation domain. In a study by Parasuraman, Hilburn, Molloy, and Singh (1991), participants monitored three flight-related functions that could be automated or performed manually, with a shift from manual to automatic control and back occurring every 10 minutes during the 30-minute session. When the functions were automated, participants were required to perform a supervisory control task of the automation. Results from this study showed performance benefits in all three flight functions and no evidence of costs for the three flight functions. Also, results showed that dynamic automation shifts when transitioning between levels of automation benefitted the performance of the flight-related tasks, without evidence of costs to performance following the return to manual control. While this can be used as a starting point for thinking about short-cycle automation in vehicles, the results cannot be generalized from aviation to surface vehicles without further research.

Maintenance of Driving Skills for Drivers

Another concern with the implementation of higher levels of automation (L2 and L3) is the degradation of some driving skills due to reliance on automation and lack of exposure to manual driving. At the current level of automation this does not seem to be much of an issue; as higher levels of automation become available, however, it can become much more significant. Already a recognized issue in aviation, prompting the Federal Aviation Administration (FAA) to release a safety notice recommending that pilots fly in manual mode more than using the autopilot (FAA, 2013), skill degradation can not only apply to psychomotor skills, but also for decision-making skills (Miller & Parasuraman, 2007). The maintenance of basic skills is important because, as previously mentioned, reliability of automation is still not perfect. There is a good chance that drivers will need to re-claim manual control of the vehicle at some point in time.

Awareness of the System by Drivers

Until L4/L5 technology expecting a driver to only provide destination input and then let the vehicle take care of all safety-critical functions, including monitoring the roadway exists, there will continue to be some level of shared authority between the driver and the vehicle over the tasks that make up driving. For lower levels of automation, design of vehicle automation that supports the driver's full understanding of the capabilities and limitations of the automation, as well as the driver's awareness of the automation's current state, could yield safety benefits. The failure to remain aware of the state of the automation and the overall status of the driving task, if the automation has failed, could potentially increase the likelihood of collisions.

Current Best Practices

While there is not yet enough relevant research about the current and near-term implementation of vehicle automation to develop full and specific design requirements, there is enough research to recognize some best practices that could be considered when designing and implementing vehicle automation. Table 1-3 below provides a summary of factors that may influence the effectiveness of an automation design, the best practice to follow regarding that factor, and key references that can provide more information on the best practice. These best practices can be used by designers and system planners as a starting point, however, it is still unknown how exactly they will apply when designing and implementing L2 and L3 automation.

Table 1-3. Summary of factors that can influence the effectiveness of an automation design.

Factors that Influence Effectiveness	Best Practice	Key Reference(s)
Driver Understanding of Automation	Automation should not degrade a driver's mental model of how the automation system functions.	Goodrich & Boer, 1999
Preservation of Situation Awareness	Drivers should be able to maintain good situation awareness in case of an automation failure (out-of-loop familiarity).	Endsley & Kiris, 1995; Endsley & Kaber, 1999; Seppelt & Lee, 2007
Automation-Induced Errors	Automation should not introduce new sources of driver error.	Sarter & Woods, 1995
Appropriate Level of Trust	The level of trust that drivers place in the automation should be commensurate with the capabilities of the automation. Drivers should not become over-reliant on automation and therefore unable to perform key driving tasks.	Lee & See, 2004; Muir & Moray, 1996; Lee & Moray, 1994
Behavioral Adaptation	Automation should not lead drivers to adopt "bad habits" (i.e., not paying attention to the road) that can lead to unsafe driving in some situations or in different vehicles.	Parasuraman & Riley, 1997; Wilde, 1998; Rudin-Brown, & Parker, 2004; Jamson, Merat, Carsten, & Lai, 2013
Allocation of Functions	Allocation of a function between manual and automated processes should be determined by task suitability (i.e., Fitts List, adaptive functional allocation), rather than application/engineering capabilities.	Hollnagel & Bye, 2000; Fitts, 1951; Grote, Weik, Wäfler, & Zölch, 1995; Inagaki, 2003; Hilburn, Molloy, Wong, & Parasuraman, 1993; Hollnagel, 2004
Definition of the Driver's Role	The driver's role and functions in the automated application should be clearly apparent.	Hollnagel & Bye, 2000; Inagaki, 2003
Incomplete Automation	Incomplete or "clumsy" automation should be avoided (i.e., when easy tasks are automated but complex ones remain manual) unless it constitutes an appropriate allocation of function for the application.	Wiener, 1989
Status Display Availability	Display of system status should be available on demand (i.e., a persistent visual notification).	Flemisch & Schieben, 2009
Status Display Modality	Status display modality should be consistent with or complement the type of information presented (i.e., visual for persistent information, auditory or conspicuous for change information.	Lee, McGehee, Brown, & Marshall, 2006
Change in Automation Status	Display of system status should indicate changes in system status. Status changes in critical tasks should be adequately conspicuous, but not disruptive to the driving task.	Hancock, 2007; Seppelt & Lee, 2007

Driving Automation Research and Design Guidance Development

The best practices summarized above provide the beginnings of a foundation for thinking about the DVIs of automated driving systems. These are some of the concepts considered during the process of assembling the design guidance provided in this document. However, this is far from a comprehensive foundation in terms of supporting the design of actual vehicle automation systems. Much more research is needed to provide the kind of science-based guidance that could benefit system developers and designers. In particular, further research about what information should be presented, how it should be presented (mode, location, format, location, etc.), and when it should be presented could be very helpful. Understanding how these factors apply across different levels, and within different implementations of automation are also important. To that end, research performed so far in the Human Factors Evaluation of L2 and L3 Automated Driving Concepts project has culminated in this set of human-centric design guidance for the DVI of automated driving systems. This design guidance represents both the current state of published science, as well as a beginning step for a rapidly evolving field.

This document may assist manufacturers in minimizing the unintended consequences of motor vehicle automation and help support designers in creating systems that are compatible with driver limitations and capabilities. Consistent with this goal, the development team has focused on providing a clear, relevant, and easy-to-use reference of human factors guidance for in-vehicle DVI design and operation within L2 and L3 automated driving environments. The development team has worked cooperatively with other project team members to ensure that relevant research and suggestions are integrated into the design guidance development process. Overall, the DVI design guidance is intended to:

- Be concise, clear, and easy to use.
- Include graphics-based design tools and examples that can be used by designers who are unsophisticated regarding human factors issues and practices.
- Include discussions of critical design issues and special design considerations when, for example, design trade-offs must be made or design constraints exist.
- Serve as a repository for relevant standards and guidelines.
- Support increased awareness and knowledge of relevant standards, human factors concepts, and user characteristics among DVI developers and designers.

While DVI design guidance can be a valuable tool and resource for designers, they have their limitations, and for L2 and L3 ADS, human drivers are ultimately responsible for driving safely. Also, we recognize and appreciate the complexities and challenges associated with developing automated driving systems; the design guidance is intended to augment, but not replace, the judgment and experience of DVI developers.

Due to the variety of data sources used in this document, users may be uncertain regarding the applicability of individual data sources to safety-related vs. non-safety-related DVI questions. In general, when considering the applicability of individual design topics to a specific DVI design question, users of this document should carefully consider the DVI question or issue they are addressing relative to the characteristics (e.g., objectives, research and analytical methods, limitations) of the original data sources cited, our syntheses of and conclusions regarding these data sources.

Scope of This Document

This document provides goals and guidance for the design and development of DVIs for L2 and L3 automated driving systems.

Limitations of this Document

As noted above, this document reflects an initial step in thinking about the information needs of drivers in automated driving systems and trying to translate those needs into DVI design guidance. There is relatively little published research available to support the development of detailed design specifications for the DVIs of L2 or L3 automated systems. Thus, this document is far from a comprehensive foundation in terms of supporting the design of actual vehicle automation systems. In many respects, it highlights key knowledge gaps and points towards what we do *not* yet know about the DVIs of automated driving systems. Future research may contribute to the science-based guidance that system developers and designers may appreciate. In particular, further research regarding what information should be presented, how it should be presented, when it should be presented, and what kinds of driver behavior/performance/acceptance challenges are associated with L2 and L3 systems could be beneficial to the community. Understanding how these factors apply across L2 and L3 systems (and other levels in the future), and across different implementations of automation (e.g., systems that provide longitudinal and lateral control at highway speeds vs. parking assist systems vs. systems that provide drivers assistance within traffic jams) are important issues for future research.

Organization of This Document

Beyond the Introductory chapter, this document consists of a series of chapters containing DVI design guidance. Each chapter contains a set of subtopics relevant to a specific design characteristic or element. Chapter 2 provides an overview of the format and content of these design-specific chapter topics (Chapters 3 through 8). Following the design chapters are a set of reference chapters with supplemental information which may be useful for either a specific topic or for DVI design in general. These supplemental material (Chapters 9 to 14) includes a glossary, an index, lists of abbreviations and equations used in the document, a list of additional standards and other documents related to DVI design, and a complete reference list of articles and reports specific to each chapter used to develop the design guidance. These chapters are listed below.

- Chapter 2. How to Use this Document
- Chapter 3. General DVI Guidance for Level 2 and Level 3 Automation
- Chapter 4. Message Characteristics
- Chapter 5. Visual Interfaces
- Chapter 6. Auditory Interfaces
- Chapter 7. Haptic Interfaces

- Chapter 8. Driver Inputs
- Chapter 9. Glossary
- Chapter 10. Index
- Chapter 11. Abbreviations
- Chapter 12. Equations
- Chapter 13. Relevant Documents From the United States Department of Transportation, SAE International, and International Organization for Standardization
- Chapter 14. References

Chapter 2. How to Use This Document

Two-Section Format

In this document, a consistent two-section format is used to present the individual human factors topics provided in Chapters 3 to 8. On each page the chapter title is indicated by centered, bold type within the header. As described in more detail below, the first section presents the title of the topic; an introduction and overview of the topic; a high-level design goal; supporting design guidance; a graphic, table, or figure that augments the text information; and the rating associated with the topic. The second section provides the more detailed supporting rationale for the topic, as well as special design considerations, cross-references to related topics, and a list of references. A sample topic, with key features highlighted, is shown in Figure 2-1; a detailed description of the presentation format of the topics follows.

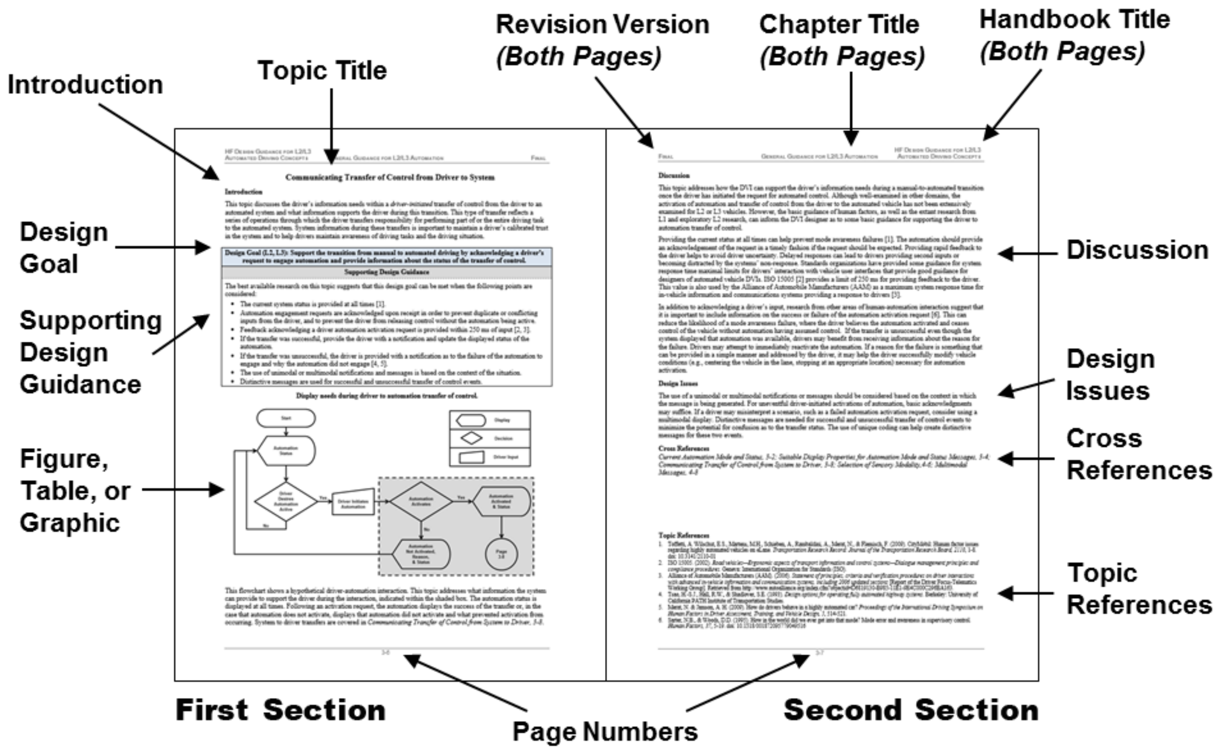

Figure 2-1. Topic format used in the guidance document.

The First Section

The topic title is indicated by centered, bold type at the top of the first page of the section.

Introduction

This subsection briefly defines the topic and provides an overview of or background for the topic area.

Design Goal

This subsection provides the high-level functional driver-vehicle interface implementation objective for the topic. This design goal: (1) specifies an objective regarding driver responses or activities that the driver-vehicle interface design is intended to support, and (2) includes the primary automation application addressed by the topic (L2, L3 or both). The objective of this section is to provide a goal *without indicating the specific ways in which the design goal must be met*. Since there may be several design approaches that could achieve the functional outcomes specified by the design goal, this level of guidance provides system and application developers with flexibility for meeting the goal with alternative design and implementation approaches.

Design Guidance

This subsection provides the best-available design information from the literature, including specific, quantitative design parameter values, if available, that can be incorporated into a driver-vehicle interface that satisfies the design goal. This represents the most directly "actionable" information presented in each topic, although the level of specificity may vary depending on available research. A key goal within this subsection is to present the design assistance clearly and succinctly, with a minimal amount of clutter. Where individual information in this subsection reflects a direct quote, or has a direct source, the source is cited. Often, information presented here reflects a synthesis of the findings, conclusions, or results from several sources, not just a single source. Also, it may reflect the judgement of the authors, after the reviews and analyses of the relevant data sources have been completed. In general, the Discussion subsection (discussed below) is intended to provide users of this document with support and rationale for the design information provided.

Figure, Table, or Graphic

This subsection provides a figure, table, or graphic to augment the design topic. This figure, table, or graphic might take many forms, including: a drawing depicting a generic application of a design principle or a design issue, a flowchart of measurement procedures for the design topic, a table that summarizes the design topic, or schematic examples of particular visual warnings. The figure, table, or graphic will provide "at-a-glance" information to support the use of the design information.

The Second Section

Discussion

This subsection, which always starts on a new page, briefly summarizes the rationale behind the choice of the supporting design guidance provided. The discussion can take many forms, including a brief review of applicable empirical studies, references to traditional design practice, or an analysis of relevant information. The discussion is presented primarily to help designers understand the design guidance and to help them explain or justify the guidance to others involved in developing a system or application.

Design Issues

This subsection presents special design considerations, design cases (e.g., older driver capabilities), or other concerns that may impact the effectiveness of the driver-vehicle interface design. Design issues are only included on an "as-available," "as-needed" basis; not all topics include a design issue subsection.

Cross References

This subsection lists the titles and page numbers of other topics within the guidance document that are particularly relevant to the current topic.

Topic References

This subsection lists the references associated with the formulation of the design topic. Each of these references will already have been noted within the text of the design topic, and assigned a reference number. It provides a quick way for designers to identify the source of the design information and for the authors to source the information.

Selection of Font Sizes in This Document

Note that the font sizes occasionally change in this document—this is deliberate. In general, the individual DVI design topics in Chapters 3 to 11 are presented using a 10-point font to maximize the content of the topics in as few pages as possible. In these chapters, the topic references might be presented in an even smaller font, depending on space constraints. The remaining chapters, including the tutorials and the "back matter" (i.e., glossary, index, references) are presented using a 12-point font.

Chapter 3. General Design Guidance for Level 2 and Level 3 Automation

This chapter provides design guidance for facilitating the relationship between the driver and automation systems so that drivers can engage the system appropriately. Drivers may benefit from a good understanding of their automation system, including the signals and mechanisms for transfer of control to the system and back again to the driver. This guidance addresses design issues that support drivers in relinquishing primary control of their vehicle, assist them in retaking the primary role of driving as workload changes, and monitoring the status of their system activities. Of importance is the ability of the system to reconnect the driver when he or she has become distracted by either secondary tasks or through the lack of focus on driving tasks that follows handover of control to the system.

The following topics are included in this chapter.

- Current Automation Mode and Status
- Suitable Display Properties for Automation Mode and Status Messages
- Communicating Transfer of Control from Driver to System
- Communicating Transfer of Control from System to Driver
- Developing and Maintaining Driver Mental Models
- Automation Etiquette
- Special Considerations for Level 2 and Level 3 Automation
- Developing Driver Training Material for Automated Driving System Applications

Current Automation Mode and Status

Introduction

This topic provides information about communicating the current mode and status of the automation to drivers. Automation mode refers to the type or level of automation that is active at a particular time. This includes the specific driving functions that are automated and that are relevant for driver understanding of the system operation. The status of automation refers to the information about the system overall, including mode, that is communicated to the driver. Appropriate status feedback about automation mode and status is important for: (1) maintaining drivers' situation awareness, (2) communicating if their requests have been received by the automation, (3) informing drivers if the system actions are being performed properly, or (4) informing drivers if problems are occurring (Toffetti et al., 2009). Providing status information is a key part of meeting NHTSA's human factors objectives of allowing drivers to safely transition between automated and manual vehicle operation and communicating relevant information about the safe operation of the vehicle effectively to the driver (Strickland, 2013).

Design Goal (L2, L3): Display the information that drivers need to maintain an understanding of the current and impending automation state and modes.

Supporting Design Guidance

Based on the best available literature, the information in the table below shows the types of status information that can be provided to the driver about the automation, and considerations for presenting this information.

Information Type	What Information to Provide	Why Information is Provided
System activation or on/off status	A display indicating which automation mode is currently active, if at all.	To support driver awareness of current automation mode when the driver seeks this information.
Mode transition status	A display indicating that a transition in automation mode is occurring or that one will occur in the near future.	Under normal operating conditions, this information is presented to help drivers maintain awareness of the driving tasks.
Confirmation of successful transfer from automated to manual control	A display or message confirming for the driver that control has been transferred to the driver as they would expect, or communication of a failed/incomplete transfer of control if the transfer is unsuccessful.	To indicate a successful transfer of control from the automation system to the driver.
System fault or failure	A display or message indicating that part of the system has failed or is not functioning correctly.	To alert drivers that they must intervene in and reclaim control of driving tasks that have previously been performed by the automation as a result of a system fault or failure.

Discussion

A key consideration when developing automated driving systems is how to keep the driver aware of the current driving situation when the automation is in control of a portion of the driving tasks. Providing mode and status information about the automation can help drivers remain aware of the driving task even if he/she is not performing it and can help drivers understand how the automation system works (Sarter, Woods, Billings, 1997).

System activation or on/off status: System activation or on/off information should be provided to the driver, even though the driver may know this type of information about the system. In a simulator study investigating vehicles that were going to be driven manually and automatically, Toffetti et al. (2009) provided drivers with a pre-activation message, communicating that the eLane (automation) system would be active in 200m. Once the vehicle was in the eLane area, a second message was provided to drivers indicating that the system was ready to use. Knowing the automation system was active helped drivers know when they could transfer control to the automation since there were multiple activation parameters that needed to be satisfied before the transfer could occur.

Mode transition status and confirmation of successful transfer from automated to manual control: If the automation system detects a situation that it cannot handle, an impending transition in automation mode from system to driver should be communicated if possible (in the case of L2 automation, and must be communicated in the case of L3 automation). This information should direct the driver's attention to the transition. In the Toffetti et al. study (2009), the system gave drivers a message a few minutes before deactivating. The majority of drivers (85%) reclaimed control of the vehicle in response to the deactivation message while the other 15% of drivers did not. With L3 automation, drivers will need sufficient time to reclaim control of the vehicle as they may be engaged in non-driving activities. Messages indicating the driver will need to take control soon can benefit drivers (Blanco et al., 2015; see Chapter 4). After the transfer of control has occurred, the driver must receive information confirming that control has been transferred back to him/her as expected (see topics *3-6* and *3-8*). Mode transition status information should be communicated to the driver under normal operating conditions to help the driver maintain awareness of system function and driving tasks.

System fault or failure: When an automation function or system detects that it has stopped functioning as it was designed to, this may need to be communicated to the driver depending on the effect upon the driver's tasks. If only part of the automated system stops functioning, resulting in partial automation, this may need to be communicated to the driver as well. In response to a system failure, either partial or full, information regarding the specific failure could be communicated if there are specific actions the driver needs to take in response to the failure. A study of L3 automation did not identify differences in driver responses to immediate take control requests based on the presence or absence of a visible external hazard (Blanco et al., 2015; see Chapter 4).

Design Issues

Tracking or external input status: For automation systems that use external inputs, information could be communicated to the driver indicating that the automation is detecting and receiving these necessary inputs. If the system is not receiving these inputs, but the sensor or device that gathers these inputs is functioning properly, it may indicate that something in the environment is preventing the sensor from gathering this information. An example of this is a lane keeping system having trouble keeping the vehicle in the lane due to faded lane markings on the road. If this information is provided to the driver, it should be provided in a way that does not interfere with the driving task (Seppelt & Lee, 2007). The decision of whether to provide this information or not is dependent upon a number of factors. Further research may assist with this decision by determining if drivers find the information useful and what benefits and dis-benefits may be associated with its use.

Cross References

Suitable Display Properties for Automation Mode and Status Messages, 3-4; Communicating Transfer of Control from Driver to System, 3-6; Communicating Transfer of Control from System to Driver, 3-8

Topic References

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5. Blanco, M., Atwood, J., Vasquez, H. M., Trimble, T. E., Fitchett, V. L., Radlbeck, J., ... Morgan, J. F. (2015, August). *Human factors evaluation of level 2 and level 3 automated driving concepts* (Report No. DOT HS 812 182). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/sites/nhtsa.dot.gov/files/812182_humanfactorseval-l2l3-automdrivingconcepts.pdf
6. Seppelt, B. D., & Lee, J. D. (2007). Making adaptive cruise control (ACC) limits visible. *International Journal of Human-Computer Studies*, *65*, 192-205.

Suitable Display Properties for Automation Mode and Status Messages

Introduction

This topic discusses message display properties for communicating automation mode and status information to the driver. Status messages can be used in a range of ways and can have different functional objectives. Display properties are important because the method used to communicate automation mode and status can be matched with the nature of the information to facilitate communication and appropriate driver responses.

Design Goal (L2, L3): Present status information in a way that is compatible with the purpose of the information being communicated and the expected driver response.

Supporting Design Guidance

The best available research suggests that this goal can be met when designers provide:

- *Continuously available information* on a dedicated display to communicate static status information that the driver can access in a self-paced manner. Visual displays are suitable for this type of information because they can be displayed continuously (Deatherage, 1972; Seppelt, & Lee, 2007).
- *Temporary, as needed, information* with a clear onset in time to communicate time-dependent information, especially a status that requires a driver to take action in the driving task. Auditory and haptic signals are suitable for this type of information because these signals are omnidirectional and have a clear onset point (Deatherage, 1972).
    - *Salient information* to communicate important, time-critical, information that commands the driver's attention. Auditory and haptic signals are suitable for this type of information because they can quickly re-orient the driver's attention (Deatherage, 1972; Parasuraman & Riley, 1997).
    - *Non-salient information* to communicate non-urgent, non-time-critical, information that notifies the driver of automation mode and status, but does not interfere with the driving task. Visual displays are suitable for this type of information because they can be viewed as the driving task allows and do not take the driver's attention away from the driving task (Deatherage, 1972; Arroyo, Sullivan, & Selker, 2006).
- *A simple display* to communicate basic information about the mode or status of the automation to the driver. Auditory signals or visual displays are suitable for communicating this type of information, but choosing which modality to use depends on the purpose of status information (Deatherage, 1972).
    - *A complex display* to communicate detailed information about the mode or status of the automation to the driver. Speech (for verbal messages) or visual displays are suitable for communicating this type of information (Deatherage, 1972; Stanton, Dunoyer, & Leatherland, 2011).

Application of design guidance to specific status message types.

Type of Mode or Status Information	Saliency	Timing	Complexity	Example
System Activation or On/Off Status	Non-salient	Continuously available	Simple	A light indicating that the automation system is on.
Mode Transition Required	Salient	Temporary, as needed	Simple	A tone and a "Place hands on steering wheel" speech message.
Confirmation of Successful Manual Override/Mode Transition Success	Non-salient	Temporary, as needed	Simple	An icon and a tone indicating that the automation will disengage in the near future, requiring the driver to reclaim control of the vehicle.
Tracking or External Input Status	Non-salient	Continuously available	Complex	A "radar" type display indicating the vehicle that the ACC system is tracking and functioning (Stanton, Dunoyer, & Leatherland, 2011).
An Error or Bad Data Resulting in Partial or Imperfect Automation	Salient	Temporary, as needed	Complex	A tone and a flashing icon indicating to the driver that the system is not functioning normally and that he/she needs to reclaim control of the vehicle.

Discussion

While it is important to communicate the current automation mode and status to drivers, the display properties used to communicate this information are equally important. The following discusses the various display properties and how they should be used to communicate mode and status information.

Providing continuously available information can help drivers understand how the automation system functions under both normal and non-normal operating conditions, such as a failure, which is an important part of helping drivers develop appropriate reliance on the automation system. If drivers understand how the system functions and they rely on it, they are more likely to use it than if they do not understand how it functions and therefore do not rely on it (Parasuraman and Riley, 1997). Seppelt and Lee (2007) investigated the use of an ecological interface design (EID) display to provide a visual representation of ACC behavior. With the EID display, drivers were better able to respond to ACC failures and the continuous information about the automation system and the roadway state helped drivers rely on the automation appropriately when detecting and responding to the failures.

Continuously available information should be non-salient, meaning that it does not take the driver's attention away from the driving task, but should be available when the driver looks for it or have reached a point in the driving task that they can take-in the information (Sarter, Woods, & Billings, 1997). The use of continuously available information mostly applies to L2 automation, as with this level of automation, the driver is still expected to monitor the roadway and for safe operation of the vehicle, meaning he/she will still be engaged in the driving task to a certain extent.

Mode and status information that is presented in response to an event occurring, such as a take-over request from the automation to the driver or a system failure, is different from continuously available information because it is often time-dependent information and requires the driver to take action. This type of information should direct or reorient the driver's attention to the driving task. The communication of this information differs between Levels 2 and 3 of automation. With L2, drivers are expected to be able to reclaim control from the automation on short notice, while in L3 drivers are still expected to be able to reclaim control of the vehicle, yet on a more infrequent basis and with a sufficient and more comfortable transition time than with L2. Toffetti et al. (2009) investigated the use an acoustic interface and a vocal interface to indicate that the driver must reclaim control of the vehicle across three messages (pre-message, first, and final message). In response to the automation deactivation message, at the pre-message step more drivers took control in response to the vocal interface (55%) compared to the acoustic interface (40%) and after the first message, more drivers with the acoustic interface (50%) took control compared to the vocal interface (35%).

Display complexity is another factor that must be considered when communicating automation mode and status information. As mentioned on the previous page, a simple display should be used to communicate basic mode or status information, while a complex display should be used to communicate more detailed mode or status information. Stanton, Dunoyer, and Leatherland (2011) investigated the use of three interfaces to communicate that the lead vehicle being tracked by the Stop & Go ACC system had changed. When using the "radar" type display, drivers were better able to a detect change in the target vehicle being tracked by the Stop & Go ACC system than when using the icon interfaces.

Design Issues

Beyond simple, salient, messages, sometimes messages must communicate a higher sense of urgency, e.g., a transfer of control. In L3 automation, the message should be intrusive, but in a non-urgent way because the transfer of control will happen in the future when driver have a lot of time to prepare. Conversely, in L2 automation drivers must take control as soon as possible. Therefore, the message needs to be salient, attention-getting, and communicate a sense of immediacy.

Cross References

Current Automation Mode and Status, 3-2; Selection of Sensory Modality, 4-6; Perceived Urgency of Auditory Warnings, 6-2

Topic References

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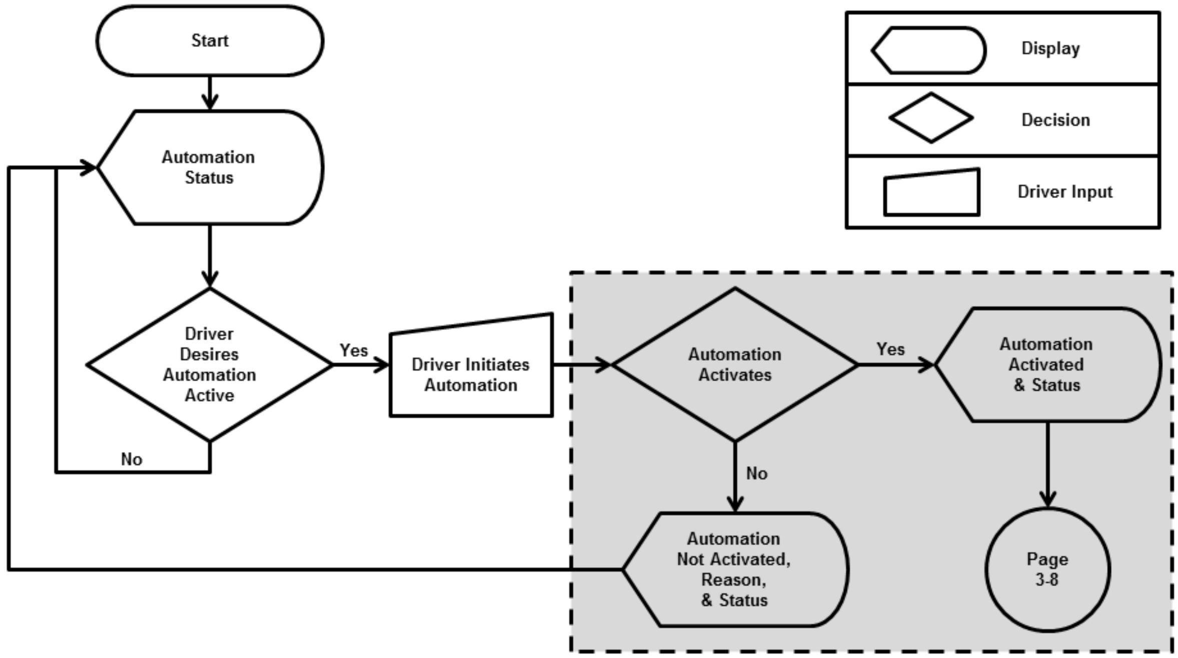
Communicating Transfer of Control From Driver to System

Introduction

This topic discusses the driver's information needs within a *driver-initiated* transfer of control from the driver to an automated system and what information supports the driver during this transition. This type of transfer reflects a series of operations through which the driver transfers part of or the entire driving task to the automated system. System information during these transfers is important to maintain a driver's calibrated trust in the system and to help drivers maintain awareness of driving tasks and the driving situation.

Design Goal (L2, L3): Support the transition from manual to automated driving by acknowledging a driver's request to engage automation and provide information about the status of the transfer of control.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when the following points are considered: The current system status is provided at all times (Toffetti et al., 2009). Automation engagement requests are acknowledged upon receipt to prevent duplicate or conflicting inputs from the driver, and to prevent the driver from releasing control without the automation being active. Feedback acknowledging a driver automation activation request is provided within 250 ms of input (ISO 15005, 2002; Alliance of Automobile Manufacturers, 2006). If the transfer was successful, provide the driver with a notification and update the displayed status of the automation. If the transfer was unsuccessful, the driver is provided with a notification as to the failure of the automation to engage and why the automation did not engage (Tsao, Hall, & Shadlover, 1993; Merat & Jamson, 2009). The use of unimodal or multimodal notifications and messages is based on the context of the situation. Distinctive messages are used for successful and unsuccessful transfer of control events.

Display needs during driver to automation transfer of control.



This flowchart shows a hypothetical driver-automation interaction. This topic addresses what information the system can provide to support the driver during the interaction, indicated within the shaded box. The automation status is displayed at all times. Following an activation request, the automation displays the success of the transfer or, in the case that automation does not activate, displays that automation did not activate and what prevented activation from occurring. System to driver transfers are covered in *Communicating Transfer of Control from System to Driver, 3-8*.

Discussion

This topic addresses how the DVI can support the driver's information needs during a manual-to-automated transition once the driver has initiated the request for automated control. Although well examined in other domains, the activation of automation and transfer of control from the driver to the automated driving system have not been extensively examined for L2 or L3 systems. However, the basic guidance of human factors, as well as the extant research from L1 and exploratory L2 research, can inform the DVI designer as to some basic guidance for supporting the driver to automation transfer of control.

Providing the current status at all times can help prevent mode awareness failures (Toffetti et al., 2009). The automation should provide an acknowledgement of the request in a timely fashion if the request should be expected. Providing rapid feedback to the driver helps to avoid driver uncertainty. Delayed responses can lead to drivers providing second inputs or becoming distracted by the systems' non-response. Standards organizations have provided some guidance for system response time maximal limits for drivers' interaction with vehicle user interfaces that provide good guidance for designers of automated driving system DVIs. ISO 15005 (2002) provides a limit of 250 ms for providing feedback to the driver. This value is also used by the Alliance of Automobile Manufacturers (AAM) as a maximum system response time for in-vehicle information and communications systems providing a response to drivers (AAM, 2006).

In addition to acknowledging a driver's input, research from other areas of human-automation interaction suggest that it is important to include information on the success or failure of the automation activation request (Sarter & Woods, 1995). This can reduce the likelihood of a mode awareness failure, where the driver believes the automation activated and ceases control of the vehicle without automation having assumed control. If the transfer is unsuccessful even though the system displayed that automation was available, drivers may benefit from receiving information about the reason for the failure. Drivers may attempt to immediately reactivate the automation. If a reason for the failure is something that can be provided in a simple manner and addressed by the driver, it may help the driver successfully modify vehicle conditions (e.g., centering the vehicle in the lane, stopping at an appropriate location) necessary for automation activation.

Design Issues

The use of a unimodal or multimodal notifications or messages should be considered based on the context in which the message is being generated. For uneventful driver-initiated activations of automation, basic acknowledgments may suffice. If a driver may misinterpret a scenario, such as a failed automation activation request, consider using a multimodal display. Distinctive messages are needed for successful and unsuccessful transfer of control events to minimize the potential for confusion as to the transfer status. The use of unique coding can help create distinctive messages for these two events.

Cross References

Current Automation Mode and Status, 3-2; Suitable Display Properties for Automation Mode and Status Messages, 3-4; Communicating Transfer of Control from System to Driver, 3-8; Selection of Sensory Modality,4-6; Multimodal Messages, 4-8

Topic References

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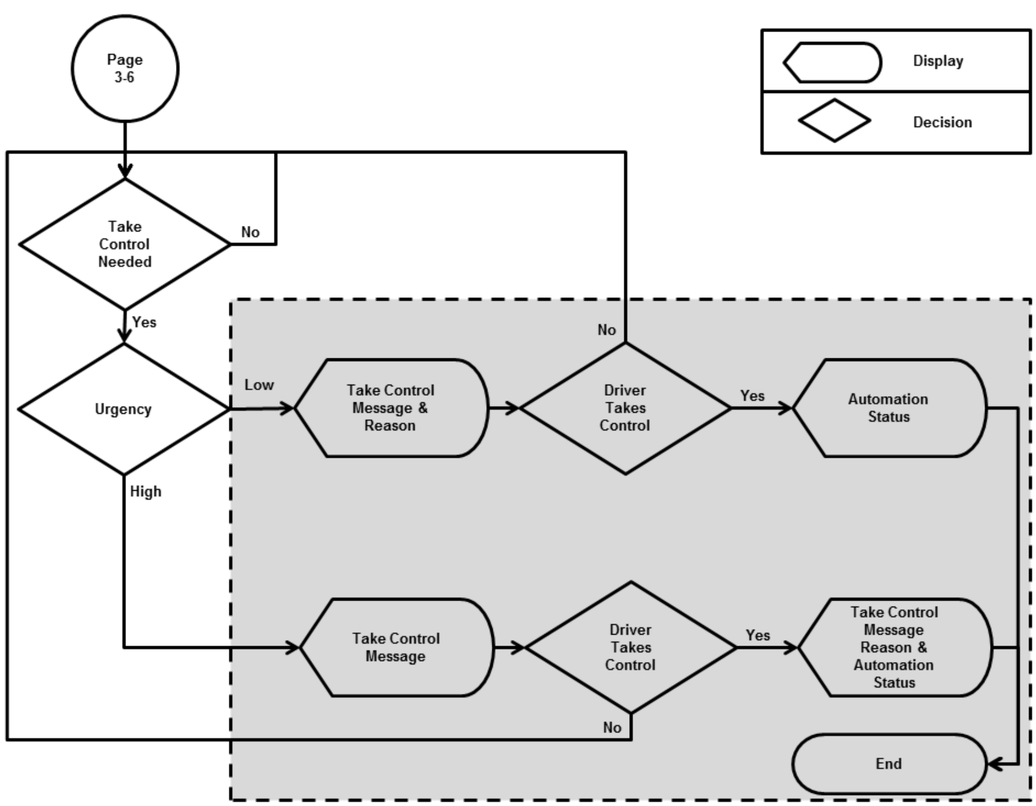
Communicating Transfer of Control from System to Driver

Introduction

This topic discusses the driver's information needs of a *system-initiated* transfer of control from an automated system to the driver and what information supports the driver during this transition. Transfer of control can range from gradual and expected by the driver to immediate and unexpected. Consequently, providing drivers with information to support a safe transition from automated to manual vehicle control in all circumstances may be beneficial.

Design Goal (L2, L3): Support the transition from automated to manual driving by providing information about the need for the driver to take manual control.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when the following points are considered: • The driver is provided with information on when they need to take control (Gold, Damböck, Lorenz, & Bengler, 2013; Blanco et al., 2015). • The driver is provided with information on how to take control if a specific control input is required (Toffetti et al., 2009). • The driver is provided with information on why the driver needs to take control. For time-critical situations, this may be a simplified "take control" message. For less time-critical situations, more information may be provided. • The current system status is provided at all times, allowing the driver to validate the disengagement (Sheridan & Parasuraman, 2005). • Notifications and messages related to a "take control" message are multimodal. (Blanco et al., 2015; Toffetti et al., 2009; Brookhuis, van Driel, Hof, van Arem, & Hoedemaeker, 2008). • Any collision avoidance system messages are provided to the driver, if applicable.

Display needs during automation to driver transfer of control.



This flowchart shows a hypothetical driver-automation interaction. This topic addresses information the system can provide to support the driver during the interaction, indicated within the shaded box. The urgency of the request is considered in what type of message to provide to the driver. The reason for the take control message is provided depending on the time critical nature of the request. Driver to system transfers are covered in *Communicating Transfer of Control from Driver to System* (3-6).

Discussion

The “take control” request should inform the driver about when to take control. A CityMobil study examining an L2-type automated driving included a three-stage warning prior to emergency braking at the end of the automated travel lane (Toffetti et al., 2009). Many drivers took manual control at the first warning issuance, and the majority of drivers had taken control after the second warning. Providing earlier “take control” requests can aid drivers in transitioning to manual control. A simulator evaluation of L3 driving used a “take control” scenario with either a 5 s or 7 s time-to-collision (TTC) used as the “take control” request issuance point (Gold, Damböck, Lorenz, & Bengler, 2013. The amount of steering maneuvers increased with a greater amount of warning (i.e., the 7 s. TTC) and the amount of braking maneuvers decreased. Drivers in the 7 s. TTC condition could sample more roadway information and thus steer the vehicle around the obstacle. In an L3 study where a 40 s duration staged alert was provided, drivers took control on average 17.0 s post-alert issuance; all drivers took control before the alert escalated to a more urgent level (Blanco et al., 2015; see Chapter 4).

Information about how the driver should take control should be provided, if applicable. If the driver should perform a certain input, such as taking manual control of steering (Toffetti et al., 2009) this information should be clearly provided. Guidelines from the Automated Highway System project recommended against limiting the methods a driver can use to take manual control of the vehicle (Levitan, Bunus, Dewing, Reinhart, Vora, & Llaneras, 1997), and cruise control (an L0 automation system most drivers are familiar with) similarly allows drivers to take manual control through multiple means.

The status of L2 or L3 automation following a temporary driver manual input should be clearly communicated to the driver (indicating if the automation is still active and in control) (Sheridan & Parasuraman, 2005). As a safety critical message, take control messages should be provided in a multimodal manner. Simulator studies of L1-type automated systems have used a visual icon for system status accompanied by an auditory signal to indicate when the system status changed (Brookhuis, van Driel, Hof, van Arem, & Hoedemaeker, 2008). Evaluations of L2-type automation have used a constant visual status message with visual and auditory notifications for transition states (Toffetti et al., 2009), or a visual-tactile combination (Blanco et al., 2015; see Chapter 2) to indicate this status.

Design Issues

When communicating transition information to the driver, a key question is how to balance the complexity of information provided against the time available to provide this information. In the absence of research specific to L2 and L3 automation, guidance from driver warnings (see topic *4-4*) should be followed and information should be presented in the simplest manner supporting a timely and effective driver response. Providing the reason for the “take control” request may be beneficial for supporting mental models. While potentially inappropriate during urgent “take control” requests, information about the reason for the “take control” request may prevent the driver from attempting to reengage automation in the presence of a limiting condition and helps support the formation of functionally-accurate mental models of the system (see topic *3-10*). Providing the current automation status allows drivers to verify the automation disengaged (Sheridan & Parasuraman, 2005). Relevant safety warnings (e.g., collision warnings) should be provided.

The guidance in this topic does not address transfers between L2 and L3 automation. Insufficient research exists to provide an understanding of what is needed to support transitions between higher automation levels (i.e., L3 to L2) and how to ensure the driver begins performing the monitoring tasks required at that point. ACC provides a similar parallel in that SAE standards do not permit ACC to transition to normal cruise control (SAE J2399, 2003). However, some simulator research suggests that drivers may benefit from a supportive level of automation during a transition (Gold, Lorenz, Damböck, & Bengler, 2013).

Cross References

Current Automation Mode and Status, 3-2; Suitable Display Properties for Automation Mode and Status Messages, 3-4; Communicating Transfer of Control from System to Driver, 3-8; Message Complexity, 4-4; Developing and Maintaining Mental Models, 3-10

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Developing and Maintaining Driver Mental Models

Introduction

This topic discusses considerations for designing an automation system that supports drivers developing and maintaining a functionally accurate mental model of how the automation system operates. A mental model encompasses the user's knowledge of an automated system's purpose, how it functions, and how it is likely to function in the future (Goodrich & Boer, 2003). Drivers with a functionally accurate mental model of the automation may be more likely to avoid errors based on incorrect assumptions about system operation, recognize a failure if it occurs, and use the automation appropriately.

Design Goal (L2, L3): Support the development and maintenance of a functionally accurate mental model of the automated system through design and training.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when the following points are considered: Provide training or information to support the formation and refinement of a functionally accurate mental model (Redding, Cannon, & Seamster, 1992; Cassidy, 2009). Provide information about the system at a level of detail that can be understood. The automation may best be described as a set of tasks or functions, not in terms of sensors and control systems. The information's level of specificity may be geared towards relevant details for the DVI and the driver's direct experience with the system without the inclusion of unnecessary details. [4] Automation works in a consistent manner and training material are consistent with the automation's operation.

Presenting information in a way that supports drivers' mental models.

Suggested	Not Suggested	Example for a Hypothetical L2 Highway-speed System
Describe automation as a set of tasks or functions and how they relate to the driver and driving task.	Describe automation in terms of the sensors and controllers.	*Not Recommended*: Training manual describes the system as using a near-infrared camera and machine vision algorithms to detect lane markings. *Better*: Training manual describes the system as looking for lane markings.
Present information at the most basic level that provides the needed information.	Present jargon or complex information, such as technical information, unnecessarily.	*Not Recommended*: Training manual describes the ACC function as a sensor fusion between machine vision- and radar-based sensors. *Better*: Training manual describes the system as constantly measuring the distance between your vehicle and objects in front of your vehicle.
Use an appropriate level of specificity, focusing on relevant details.	Provide unnecessary details or needless information.	*Not Recommended*: DVI provides status and continuously updated distance values for lane keeping and headway separately. *Better*: DVI provides a single presentation of automation status.

Discussion

Drivers have mental models that help them understand a system's current performance as well as extrapolate its likely future behavior (Goodrich & Boer, 2003). While drivers have existing mental models for common automation features, such as cruise control, they will have vague or non-existent mental models for the first implementations of L2 and L3 automation. Thus, mental models will be developed through instruction, training, and use.

Unfamiliar automation can be paired with instruction and training to support the formation, refinement, and maintenance of the driver's mental model. Research in human-automation interaction, such as air traffic control, has identified that having a functionally accurate mental model for automated systems is a central aspect of reaching a level of expertise with the system (Redding, Cannon, & Seamster, 1992). Additionally, having a functionally accurate mental model affects an operator's level of trust in an automated system (Cassidy, 2009). Automated decision aid research has suggested that operators with a functionally accurate mental model of an automated system are better able to identify automation errors (Wilkison, 2008).

A simulator study of an L1 automation technology (ACC) examined the formation of drivers' trust and conceptual models over 10 days (Kazi, Stanton, Walker, & Young, 2007). Results indicated that drivers' conceptual models tended to be consolidated by the fourth day. Additionally, despite specifically stating that the ACC system did not include a collision avoidance feature, 33 percent of participants incorrectly described collision avoidance as a system component. Further analysis indicated that some drivers were confusing the headway maintenance feature of ACC with a collision avoidance maneuver. While not representative of ACC's real-world performance, this research highlights the importance of information presentation.

In advanced systems, some complex information cannot be processed until it has been stored in a schematic form in long-term memory (Pollock, Chandler, & Sweller, 2002). Depending on the implementation, automation may be a highly complex system from a human-automation interaction perspective. Some best practices from prior human factors research into automation are applicable, including presenting information at an appropriate level and at the appropriate level of detail (Wiener, Chute, & Moses, 1999).

Support formation of functionally accurate mental models by having automation work in a consistent manner. In the case of the L1 ACC automation technology, Goodrich and Boer (2003) note that the utility of the automation is a function of not only the driver's understanding of the vehicle-environment interaction but also the driver's understanding of the automation. When the ACC system behaves in a manner consistent with that of a reasonable driver, the driver's mental model of the system will be supported and the driver will be more likely to intervene when needed (Goodrich, Boer, & Inoue, 1999). While this research examined the case of an L1 automated system, the same guidance likely applies to other monitored automation types that fall under L2. Additionally, any information about the system provided to the driver should be consistent with how the system will function.

Design Issues

A driver's mental model of how a system operates, performs, and will likely perform helps determine the likelihood that the system will be ignored, used correctly, or misused/misapplied. Drivers of the first L2 and L3 automated driving systems will likely have weak, incorrect, or absent mental models of early automated systems. Further, it is unknown what differences may manifest between drivers' mental models of L2 and L3 automation. Given the myriad ways drivers can interact with automation, design should be sensitive to, and supportive of, the formation of functionally accurate mental models.

Cross References

Current Automation Mode and Status, 3-2; Developing Driver Training Material for Automated Driving System Applications, 3-14

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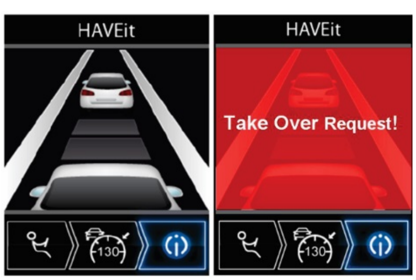
Special Considerations for Level 2 and Level 3 Automation

Introduction

This topic discusses special considerations associated with L2 and L3 automation. The level of automation can determine how involved the driver must be in monitoring the environment to ensure the safe operation of the vehicle. Humans, however, are poor at performing vigilance and monitoring tasks. Automation may benefit from being designed to provide information to drivers in a way that promotes a level of supervision by the driver that is appropriate for the level of automation.

Design Goal (L2, L3): Encourage adequate driver supervision relative to the requirements of the level of automation.
Supporting Design Guidance
Potential challenges to drivers using L2 and L3 automation arise from driver task underload. The following guidance is based on the best available research on this topic and provide general information related to addressing these challenges. Automation that optimizes drivers' workload may promote situation awareness and assist in maintenance of an appropriate level of vigilance during automated driving. Automation that may need driver intervention may benefit from having an awareness of the driver's status as part of supporting transitions from automated to manual driving. There may be benefits from employing strategies that engage the driver's attention when deemed necessary. L2 automation may perform best when designed to: – Clearly indicate the level or mode of automation – Encourage drivers to attend to forward roadway conditions (Blanco et al., 2015; see Chapter 3) – Provide alerts for system failures and limitations (Salinger, 2012; Hoeger et al., 2011) L3 automation may perform best when signals used to indicate or request a transition from automation to manual control are salient, distinctive, and unambiguous in order to capture drivers' attention and promote understanding of the automation state.

A. Display indicating request to reclaim control from automation.



B. Message to capture inattentive drivers' attention.

C. Flashing LEDs in the windscreen at right to capture inattentive drivers' attention.

A. Figure 263, use and modification of fifth image, B. and C. from Figure 133]. Adapted from Hoeger et al. (2011). Used with permission.

Discussion

L2 automation requires drivers to monitor the road and remain able to take control of the vehicle at any time. L2 automation takes drivers out of the vehicle-control loop and requires them to adopt a supervisory role; however, humans generally perform poorly in the role of monitors (Kaber, & Endsley, 2004). Out-of-the-loop (OOTL) problems include complacency, vigilance decrements, loss of situation awareness, and decay of skill when relying on high-level automation compared with low- or intermediate-level automation (Kaber, & Endsley, 2004; Stanton, Young, Walker, Turner, & Randle, 2001). Stanton et al. (2001) found that drivers were less able to reclaim control of the vehicle from the automation in an emergency braking scenario when both ACC and a lane centering system (LCS) were active. Similarly, drivers' brake reaction times in a simulator study (Young & Stanton, 2007) were 1.0 s to 1.5 s longer for OOTL drivers using ACC versus manual headway keeping. Strategies should be adopted that promote situation awareness and support understanding of the automation state when drivers are out of the control loop. Such strategies may include interactive, periodic, messages that serve to engage the driver (Widmann, Salinger, Dufour, and Green, 2011), or messages based on driver monitoring systems (Blanco et al., see Chapter 3; Hoeger et al., 2011).

L3 automation requires the automation to assume a greater role for the safe operation of the vehicle, and the driver is not expected to constantly monitor the road. Consequently, the requirements for vigilance and situation awareness are reduced, but not eliminated, as compared with L2 automation. As drivers do not have to engage in driving, they may become so involved in secondary tasks (e.g., eating, reading, watching entertainment, or perhaps even sleeping) that they may entirely miss the transition message. In a driving simulator study, Carsten, Lai, Barnard, Jamson, and Merat (2012) found that drivers in vehicles with combined ACC and LCS engaged in activities other than driving (e.g., eating, listening to the radio, watching DVDs, etc.) when the automation was active, and the level of inattention to the driving environment increased proportionally with level of automation. Similarly, drivers in simulator and test track experiments (Salinger, 2012) performed relatively risky tasks, such as cell phone talking, texting, and emailing; watching DVDs; and reaching into the back compartment, during automated driving. Therefore, it may be of benefit to understand the driver's status before alerting them to a forthcoming transition. An important issue for L3 automation, then, is ensuring that the signal presented by the automation to inform drivers of the change of automation is sufficiently salient, distinctive, and unambiguous that drivers are able to quickly and easily understand the state of the automation.

Design Issues

Hoc, Young, and Blosseville (2009) assert that automation should be implemented as a human-automation cooperative system rather than simply using a task-based framework. The goal of a cooperative system is to optimize the driver's task load in order to avoid driver overload or OOTL problems. The European HAVEit demonstration project (Salinger, 2012) adopted a cooperative approach by integrating driver monitoring systems with incremental levels of automation (L0 through L2). When driver state detection algorithms determined that drivers were drowsy or inattentive, the system presented visual and/or auditory signals to capture drivers' attention and bring them back into the vehicle control or monitoring loop. Another approach to driver monitoring is to periodically provide a message to which the driver must respond. Widmann, Salinger, Dufour, and Green (2011) used elbow switches, foot switches, and steering wheel touch sensing as inputs to allow the driver to respond to these messages.

Cross References

Communicating Transfer of Control from Driver to System, 3-6; Communicating Transfer of Control from System to Driver, 3-8; Message Complexity, 4-4; Developing and Maintaining Mental Models, 3-10; *Chapter 5: Visual Interfaces; Chapter 6: Auditory Interfaces; Chapter 7: Haptic Interfaces*

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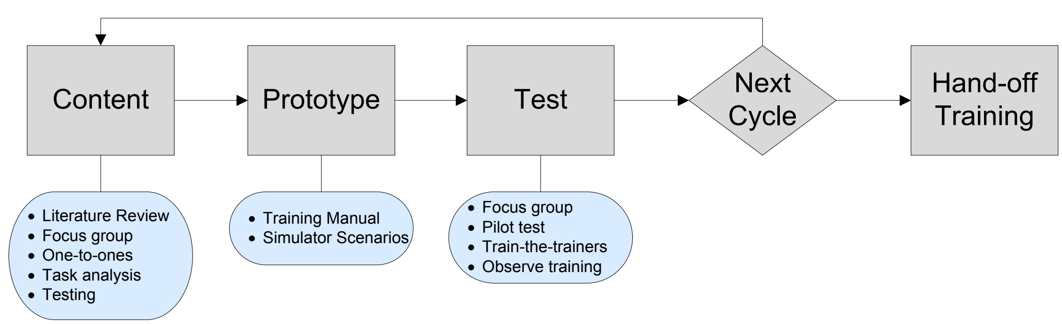
Developing Driver Training Material for Automated Driving System Applications

Introduction

Training is the process by which we acquire knowledge and skill on specific topics, systems, or applications. Many driver training programs have been developed by using curricula designers that "believe should be there" and have been minimally influenced by contemporary findings from the behavioral sciences (Brock, McFann, Inderbitzen, & Bergoffen, 2007). This topic summarizes recent findings from the behavioral research literature on several training methods that could be used to train drivers on L2 and L3 automated driving systems. This DVI design topic may be most applicable to automation applications that are especially novel or complex.

Design Goal (L2, L3): Systematically design, develop, and evaluate training for automated systems in a manner consistent with the goals of the system.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when the following points are considered: Provide information on system functionality and system limits in a driver training program (Panou, Bekiaris, & Touliou, 2010). For complex systems with many features, variable priority training (VPT) may be used. In VPT, trainees are presented a complex task divided into subtasks between which they vary their attentional priority (Boot et al., 2010; Wickens, Hutchins, Carolan, & Cumming, 2013) (e.g., divide the task into Parts A and B. Start with the trainee devoting 80% of their attention to Part A and 20% to Part B. Then, dedicate 20% to Part A and 80% to Part B. Finally, practice with 50% attention to both.). Use error-training as a strategy to reduce driver overconfidence in using an automated system and to influence trainees to generate their own coping strategies for novel situations not covered in training (Ivancic, & Hesketh, 2000). Training on the use and function of in-vehicle systems occurs after novice drivers have obtained the basic and rudimentary skills needed for safe-driving (Panou, Bekiaris, & Touliou, 2010).

Simple 5-stage iterative training design model (Graving, Easterlund, & Manser, 2011).



Content: During the initial design phases of developing a training curriculum, a first step is to obtain training content and information about general training requirements. This can be obtained through user interviews, use-case scenarios, focus groups, and task analyses. Literature searches can be useful for preparing for user-testing and obtaining information about driver tasks (e.g., previous task analyses, McKnight, & Adams, 1970). The other phases of the iterative design process can also be used to generate content for training. **Prototype:** Start by generating simple prototypes (e.g., paper-based drafts of a training manual) during this phase to test training concepts and ensure the training content is appropriate. During subsequent iterations, generate more complex prototypes (e.g., pilot-test class-room instruction or develop simulator-based scenarios) to test the functional aspects of the training program—e.g., timetables for when certain topics are covered, methods of presentation.

Test: The process of testing a prototype can be useful for obtaining additional design requirements as well as uncovering implementation issues. Testing can include observations of trainers carrying out the training program.

Next Cycle: A decision phase where the testing results are used to decide if additional iterations are required.

Hand-off Training: If testing indicates that iterations are no longer required, the training program is ready to be handed off to trainers.

Discussion

While simpler automated systems may not require specific training, some more complex automated systems may require initial training at vehicle delivery to ensure the driver has a minimum level of operating skills with the automation prior to use. Training system development should be systematic, deliberate, and informed by research findings from the instructional system design literature.

A training program may cover all features of the automation (especially if only a single type of automation is present in the vehicle) or can entail different aspects of the system itself. Training sessions should focus on the functionality of the system, including information on limitations (including when automation may not be activated or used) and any potential for malfunction (Panou, Bekiaris, & Touliou, 2010). Such training programs could highlight any significant limitation of the system for informing the driver of sudden hazards, as well as limitations based on sensing technologies used. For instance, drivers should be made aware that the highway speed automation will not change lanes to pass slower moving lead vehicles, or that the traffic jam assist feature will not remain active after a certain continuous period of time above a set speed.

Training programs should also include information on how to read and interpret the DVI, methods for activating the system, available action options for manual overrides and input during automated driving (e.g., accelerate, brake, steer, or a combination of inputs), how the system reacts to manual inputs during automated driving, and what types of control transfers may be encountered. Proper training should also provide drivers with the ability to transform and incorporate declarative knowledge (e.g., knowledge about the system) into more automatic-like actions for using the automation. Such behavioral skills can become relatively immune from deterioration in a broad range of contexts (Rasmussen, 1983).

Different training strategies may be employed to ensure that drivers gain knowledge on and retain useful driving strategies. The VPT strategy is an effective training strategy for complex tasks (Graving, Easterlund, & Manser, 2011). The method presents trainees with the whole task, which is maintained during training, but different components are systematically emphasized or deemphasized to allow more attention to be focused on specific parts while still preserving the necessary element of time-sharing of attention across the whole task (Wickens, Hutchins, Carolan, & Cumming, 2013). Drivers trained with this strategy tend to learn faster and reach higher levels of mastery compared with training programs that emphasize all components equally (Boot et al., 2010; Wickens, Hutchins, Carolan, & Cumming, 2013). In addition, the error-training strategy where learners acquire information about a task through exploration, testing self-generated hypotheses, and trial-and-error may be effective in reducing overconfidence and can help drivers develop coping strategies for scenarios not covered in training (Ivancic, & Hesketh, 2000).

In some cases, different training settings may be necessary. Drivers 70 to 89 years old benefit more after training is complete when instructors provide feedback on actual driving in addition to classroom training (Porter, 2013). As much as possible, training should provide drivers with an ability to manage the traffic events and scenarios presented during training as well as novel events not encountered during training.

Design Issues

Large in-vehicle displays with additional computing capabilities are becoming more common, providing a potential platform for embedded training (U.S. Army Training and Doctrine Command, 2003). Embedded training, or training that is integrated into and provided by the vehicle, can offer drivers the opportunity for training, guided practice, and coaching at any point in their use of the vehicle. As technologies continue to develop, embedded training may become an efficient solution to training needs.

Cross References

Developing and Maintaining Driver Mental Models, 3-10

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Incorporating Etiquette Into the Design of Automated Systems

Introduction

This topic provides information on presenting the automation to the driver in a manner that may support a driver's calibrated trust of the automated system. A strategy, often referred to as *etiquette*, is a set of heuristics that may enhance and improve a driver's interaction with the system, possibly leading to higher levels of acceptance and performance.

Design Goal (L2, L3): Provide driver-automation interactions that are interactive and collaborative in nature.

Supporting Design Guidance

Below is a list of considerations for designing automation that is collaborative and may support the driver-automation interaction process. These considerations were adapted from work by Lee and Seppelt (2012), itself based on Miller and Funk (2001). The "Corresponding Topics" column refers to a topic in this document that can provide more detail on the consideration for designing with an etiquette approach. Considerations without a corresponding topic will be discussed further in the *Discussion* section of this topic.

Considerations for Designing with an Etiquette Approach	Corresponding Topics
a) Make it very easy for the driver to override the automation.	Communicating Transfer of Control From System to Driver (3-8)
b) Avoid enabling interaction features just because they are possible.	Special Considerations for Level 2 and Level 3 Automation (3-12)
c) When appropriate, explain what is being done and why.	Current Automation Mode and Status (3-2)
d) When appropriate, allow driver selection of what functions are automated.	See *Discussion* (next page)
e) Be aware of what the driver is doing and avoid repeating or providing gratuitous and unnecessary messages.	See *Discussion* (next page)
f) Use multiple modalities to communicate.	Suitable Display Properties for Automation Mode and Status Messages (3-4); Multimodal Messages (4-8)
g) Be casual or informal only to the extent that it furthers the driver-automation interaction.	See *Discussion* (next page)

Discussion

Using an etiquette approach in automation has been shown to be beneficial for human-automation interactions and user task performance in various domains and various forms. The use of an etiquette approach can affect a user's trust or reliance on the automation system (Spain & Madhavan, 2009). The considerations listed on the previous page can be followed to design an automation system with an etiquette approach. However, every system is different and this is not a prescriptive approach to the driver-automation interaction. In all cases, designers should consider using the approach that best fits the scenario (Miller & Funk, 2001). Below, the considerations without a corresponding topic are discussed.

When appropriate, allow driver selection of what functions are automated: To facilitate a collaborative relationship between the user and the automation system, the automation system should be able to take instruction from the user about the activities it should be engaged in Miller and Funk (2001). Specifically, this means that the user should be able to change the function allocation between him/herself and the automation to fit the current situation without interference from the automation system.

Be aware of what the driver is doing and do not repeat or provide gratuitous and unnecessary messages: An example of this etiquette approach can be found in L2 and higher levels of automation in which the automation system has communicated the need for the driver to reclaim control of the vehicle by placing his/her hands on the steering wheel. Once there is positive indication that the driver has assumed control, the automation should not send another take over request to the driver. If this etiquette approach is not considered, drivers may not feel comfortable trusting the automation system because it is telling him/her information he/she already knows or is aware of, which is not assisting the driver any further than what they are already capable of without the automation. Results of a study by Parasuraman and Miller (2004) show that users rated the automation system as "rude" when it offered redundant, task-specific information because they felt like the system was telling them to "hurry up." When utilized in a military field exercise, minimizing interruptions from non-urgent messages at critical times enabled the soldier to maintain performance on the most critical tasks (Dorneich, Ververs, Mathan, Whitlow, & Hayes, 2012).

Be casual or informal only to the extent that it furthers the driver-automation interaction: When introducing a new form of guided interaction, developers have sometimes tried to be informal in the interaction format, such as the use of the anthropomorphized Microsoft Office Assistant (Horvitz, 1999). While helpful in some domains, driving is a serious, safety-critical activity and it is important to show a clear benefit to being casual, natural, or informal before introducing unnecessary embellishments and extra information.

Cross References

Current Automation Mode and Status, 3-2; Suitable Display Properties for Automation Mode and Status Messages, 3-4; Communicating Transfer of Control from System to Driver, 3-8; Special Considerations for Level 2 and Level 3 Automation, 3-12; Multimodal Messages, 4-8

Topic References

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Chapter 4. Message Characteristics

This chapter provides design guidance for developing messages that are effective for both safety and non-safety applications. For safety messages, in particular for situations where the driver is not actively monitoring the forward roadway or driving situation (as in L3 automation), drivers need to respond quickly at a time when the driving situation could potentially require high cognitive demand. Research suggests that messages presented under these conditions are most effective when they capture drivers' attention without being distracting, are clear and easily understood, aid the driver in focusing attention on the roadway and/or the potential hazard, and support the driver in making an appropriate response. In addition to safety messages, it is expected that non-critical messages may also be presented on integrated displays. Central displays in passenger vehicles may include integrated "infotainment" and navigation applications. The guidelines in this chapter discuss the issues associated with DVI messages and how to present them in a way that will enhance safety and optimize driver responses.

The following topics are included in this chapter.

- Designing Messages for Driver Comprehension
- Message Complexity
- Selection of Sensory Modality
- Multimodal Messages

Designing Messages for Driver Comprehension

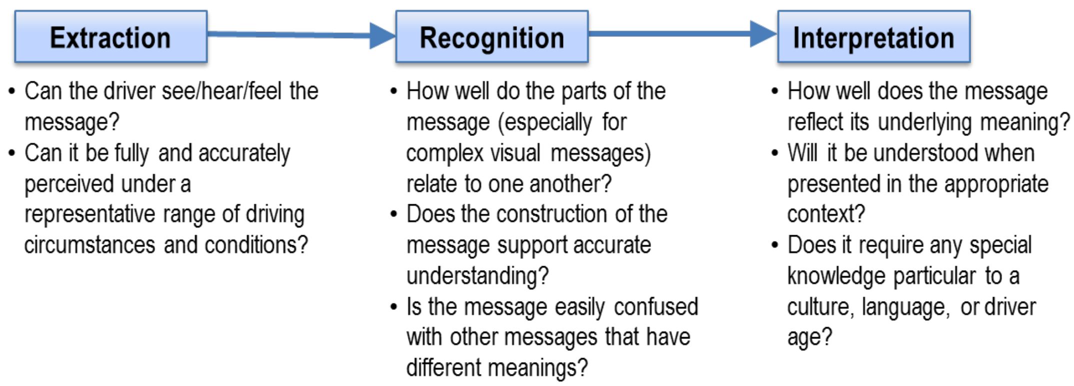
Introduction

This topic provides guidance for enhancing the comprehensibility of messages. Comprehension refers to the perceptual and cognitive processes by which drivers interpret the meaning of a message presented through a DVI. Broader conceptual frameworks that address the comprehension of in-vehicle messages are scarce, but such a process for design and evaluation is described by Campbell, Richman, Carney, and Lee (2004), which can give a foundation for this topic.

Design Goal (L2, L3): Develop and present messages that support accurate and timely comprehension by the driver.

Supporting Design Guidance

The best available research on this topic suggests that this design goal can be met if the following questions are considered when designing messages:



Design considerations for each stage of message comprehension.

Stage of Message Comprehension	Key Design Parameters to Consider
Extraction*	**Visual messages:** Character or symbol height, font, character height-to-width/stroke-width/spacing ratios, luminance and luminance uniformity, contrast, color, text labels (for icons and symbols). **Auditory messages:** Sound level, display type, loudness, fundamental frequencies, pitch. **Haptic messages:** Type, location, amplitude/intensity/frequency.
Recognition	Temporal characteristics, level of realism and detail (for icons & symbols), flash rate.
Interpretation	Use of color, cues to relative urgency, cues to external locations (e.g., sound localization), use of combined cues/messages (e.g., an auditory tone that accompanies a visual alert).

*Legibility for visual messages, complete and accurate perception of auditory and haptic messages.

Discussion

Developing effective in-vehicle messages requires a conceptual approach that applies a theoretical understanding of driver perception and performance. As discussed in Campbell, Richman, Carney, and Lee (2004), there are three stages associated with message comprehension and use: extraction, recognition, and interpretation. Extraction reflects the relationships among the driver, the message, and the environment, and is essential for a complete and accurate perception of the message. Recognition reflects the relationships among the driver, the message, and other messages or message elements. Interpretation reflects the relationships among the driver, the message, and the referent or underlying meaning associated with the message.

Also, as a result of familiarity, comprehension will be more likely when internationally agreed-upon icons, symbols, words, acronyms, and abbreviations are used in the DVI (Alliance of Automobile Manufacturers, 2006)..

Design Issues

Factors affecting comprehension: Message comprehension is affected by several factors including: semantic organization and complexity of the message, the context in which the message is presented, drivers' familiarity with the message, driver expectations and experience, memory limits, and workload. Familiarity has been found to be strongly associated with comprehension. A study reported by NHTSA (2011) found that drivers responded more slowly to a driving event (e.g., forward collision event) when they experienced an unfamiliar auditory alert. In some cases, this difficulty remained even after reading the user manual. In short, after exposure and extended use, drivers can learn to comprehend virtually any message. While even "bad" messages can eventually be effective, however, they may promote errors, require training, or involve extensive trial-and-error learning.

Testing comprehension: Comprehension tests are evaluation techniques that provide a means to determine whether a candidate message design is likely to be properly understood by typical roadway users. Several procedures can be used to measure driver comprehension of messages, including SAE J2830 Process for Comprehension Testing of In-vehicle Icons, which is an SAE Information Report within the SAE Standards series (SAE J2830, 2008). Given the possible complexity of in-vehicle messages and the real possibility of multiple safety systems within a vehicle that can present safety-critical information to the driver, it is also necessary to evaluate integrated warning systems. Cullinane and Kirn (2012) describe a laboratory methodology that can help identify comprehension/distinguishability issues prior to full system development in a controlled, repeatable, and safe setting.

Cross References

Developing Driver Training Material for Automated Driving System Applications, 3-14; Message Complexity, 4-4

Topic References

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Message Complexity

Introduction

This topic provides information on design characteristics that affect the complexity of messages. Specifically, it provides a discussion of driver needs associated with message complexity and identifies characteristics of visual, auditory, and haptic messages that affect complexity. While there is limited research specifically examining this topic in L2 and L3 automated driving systems, designing interfaces with an understanding of well-established guidance from past DVI research is advisable. Message complexity refers to the quantity and variety of basic information elements contained within a message, as well as the relationships between these elements. Message complexity is an important topic in DVI design, as messages that are too complex may not be properly perceived, comprehended, or acted upon by the driver. The information in this topic can be used by designers to determine the level of complexity that is appropriate for a DVI message and to implement DVI messages that are appropriately complex.

Design Goal (L2, L3): Present messages to the driver in the simplest form possible so the driver can readily perceive, comprehend, and act upon the information.

Supporting Design Guidance

The best available research on this topic suggests that this design goal can be met when:

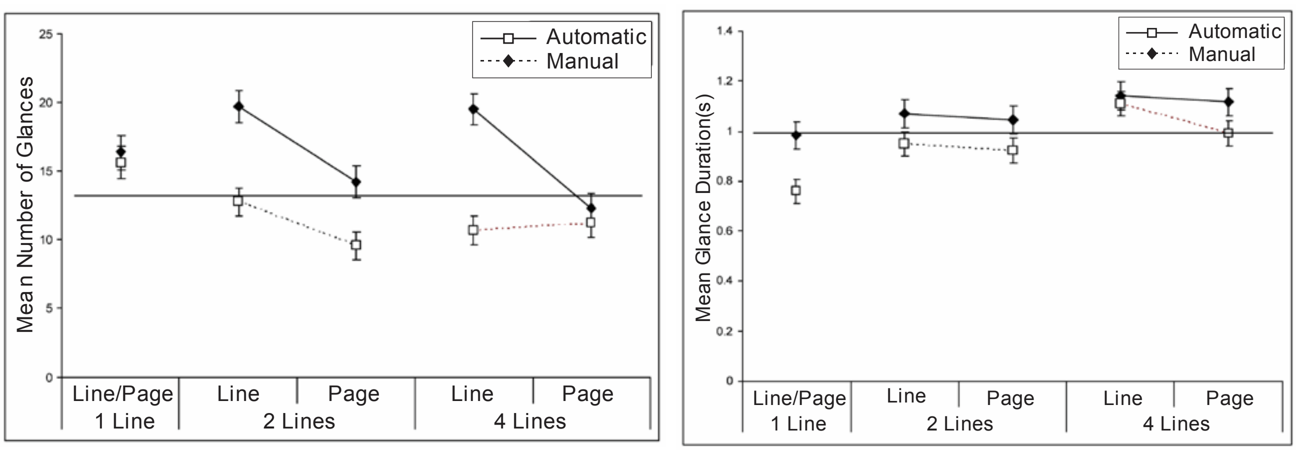
In General, information is presented in as simple of a manner as possible while ensuring messages support and add value for the driver.

Visual Messages consist of simple icons and fonts with only the necessary detail included. In text displays, the number of lines of text per-message is minimized.

Auditory Messages are simple when an immediate response is required. This could be single or grouped frequencies presented simultaneously; such as a simple tone that consists of a square wave.

Haptic Messages are simple and perceptible. Research relevant to the topic of haptic message complexity is limited.

Number of glances as a function of message complexity (McDougall, Tyrer, & Folkard, 2006).



Data recreated from Hoffman, Lee, McGehee, Marcias, and Gellatly (2005). Visual sampling of in-vehicle text messages: Effects of number of lines, page presentation, and message. In Transportation Research Record: Journal of the Transportation Research Board, No. 1937, Figure 2, p. 25 and Figure 3, p. 26. Copyright, National Academy of Sciences, Washington, DC, 2005. Reproduced with permission of the Transportation Research Board.

Discussion

Complexity in DVI messages generally refers to the amount of information provided in the message, but must also include consideration of how the information will be used by the driver as well as the value of the information to the driver. Overall, the consequences of presenting DVI messages to the driver that are too complex can include: disruption of attention toward the driving task (potentially an issue during transitions between automated and manual driving), increased eyes-off-road time, increased driver workload and possible distraction, and increased response time to critical road events.

Complexity in visual messages: Increasing the complexity of DVI messages increases cognitive demand. In Hoffman et al. (Hoffman, Lee, McGehee, Marcias, & Gellatly 2005), a medium-fidelity simulator was used to examine how message complexity (the number of text lines of a message) influenced visual sampling behaviors. Mean glance duration, variability of glance duration, and the number of glances greater than two seconds all increased as the number of lines of textual messages displayed. Visual demand was especially increased when the scrolling was manually controlled by the driver. In another study (McDougall, Tyrer, & Folkard, 2006), the speed with which participants searched icon arrays for a target was slower when icons were visually complex and when information features in icons were not grouped together to form a single object. In general, icons should be simple, with only the necessary detail included. Excessive and unnecessary amounts of detail contribute to clutter and can lead to slower and poorer comprehension (see also Campbell, Richman, Carney, & Lee, 2004, and Easterby, 2007). These findings are consistent with those from basic research going back at least 40 years that investigated—for example—reading performance as a function of various characteristics of the visual stimuli (Rayner, Pollatsek, & Alexander, 2005).

Complexity in auditory messages: Simple tones are good for gaining the attention of the driver and, if properly implemented, can be used effectively to warn of an imminent danger. Simple tones have also been shown to produce shorter reaction times than speech messages when used in conjunction with a visual display (Kiefer, LeBlanc, Palmer, Salinger, Deering, & Shulman, 1999). A recommendation from the CityMobil project was to limit auditory message length to 3 or 4 information units, with messages requiring immediate reactions being as short as possible (Martens et al., 2008). Based on the limited research in the topic, it is prudent to rely upon prior research findings and guidance (Kiefer, LeBlanc, Palmer, Salinger, Deering, & Shulman, 1999) and limit complex auditory messages to non-time critical situations.

Complexity in haptic messages: Research on haptic displays in automobiles is relatively recent and has focused on understanding what makes haptic displays perceivable to the driver and which kind of haptic warning is most compatible with the driver response appropriate for the driving hazard (see also Lerner, Kotwal, Lyons, & Gardner-Bonneau, 1996).

Design Issues

Reducing unnecessary message complexity is challenging in situations where multiple forms of vehicle automation capabilities operating at multiple automation levels (e.g., L2 highway speed driving assist and L3 traffic jam assist) are included.

Inadvertent increases in message complexity can occur in the vehicle as automation capabilities are included without integrating the DVI components in a way that supports safe driver behaviors. In the context of discussing some challenges to building and maintaining situational awareness in complex systems, Endsley (2012) discusses the problem of "complexity creep," referring to the practice of adding features and capabilities over time to systems, and how such practices complexity can reduce the interpretability of information, reduce the predictability of the system, and slow response time.

Cross References

Designing Messages for Driver Comprehension, 4-2; Selecting Character Height for Icons and Text, 5-10

Topic References

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Selection of Sensory Modality

Introduction

This topic provides heuristics and a discussion of relevant literature to support the selection of sensory modalities (i.e., visual, auditory, or haptic) for presenting messages in the vehicle environment. The mode of presentation can influence driver responses and behavior. The type of modality that is appropriate for a message depends on the driving environment (e.g., expected vehicle/cab noise and vibration, hazard scenario), the criticality of the message (e.g., hazard vs. non-hazard situations), location of visual displays, and other factors. Further, based on current industry trends, it is expected that many messages in L2 or L3 automated systems will be multimodal (presenting an auditory or haptic message accompanied by a visual message). In general, much more research and analyses are available on visual and auditory messages than on haptic. Also, haptic messages share many of the advantages and limitations as auditory messages. This topic provides information that will help designers determine which presentation modes are most appropriate for various messages.

Design Goal (L2, L3): Match the modality of messages with driver tasks, needs, and expectations in order to enhance drivers' comprehension and performance.
Supporting Design Guidance
The best available research on this topic suggests the following: **Visual messages** are best for presenting more complex information that is non-safety-critical and does not call for immediate action, and can be used to: Provide continuous lower-priority information such as automation status, navigation-related, or cautionary information. Provide spatial information. In this regard, head-up displays (HUDs) and high head-down displays (HHDDs) also have potential for presenting critical information, especially if the message has a spatial component. (e.g., location in space relative to the driver's vehicle). Provide redundant or supplemental information that accompanies auditory or haptic messages. **Auditory messages** are capable of quickly capturing the driver's attention and can be used to: Present short, simple messages requiring quick or immediate action. Present high priority alerts and warnings (e.g., take control messages); in this instance, can be used in conjunction with visual or haptic messages to provide redundant cues to the driver. In an L2 system, provide an important message to drivers in situations in which they may be distracted or looking away from a visual display (note: this may apply to haptic messages as well). Indicate the onset of a system notification, malfunction, or limitation. **Haptic messages** are capable of quickly capturing the driver's attention and can be used if: It is likely that the driver is in contact with the haptic display source (e.g., drivers will usually feel a seat vibration, but will likely not be in contact with the pedal assembly or steering wheel during L2 or L3 automated operation).

Discussion

Much has been written on the selection of visual versus auditory modes for various types of driving information and signals. Many authors have relied on the original work of Deatherage (1972), who laid out a series of useful rules for assisting designers in this task. The table below lists the original eight rules providing guidance for the selection of auditory and visual mode presentations.

General rules for selecting auditory vs. visual display modes (Deatherage, 1972).

Use Auditory When…	Use Visual When…
The message is simple.	The message is complex.
The message is short.	The message is long.
The message will not be referred to later.	The message will be referred to later.
The message deals with events in time.	The message deals with locations in space.
The message calls for immediate action.	The message does not call for immediate action.
The visual system is overburdened.	The auditory system is overburdened.
The receiving location is too bright or dark.	The receiving location is too noisy.
The user must move about.	The user can stay in one place.

Most research on automotive displays focus on presenting safety-critical messages. While this is applicable for presenting safety-critical information in automated driving systems (particularly in L2 operations), research is needed to understand how to optimally present non-safety critical information.

The advantage of auditory and haptic displays is that they are omnidirectional signals that can command attention regardless of where the driver is looking. In a simulator study, Stanley (2006) examined haptic, auditory, and multimodal (haptic and auditory) displays for a lane departure warning (LDW) system. Drivers in the haptic modality had faster reaction times than either auditory or multimodal modalities, and perceived the haptic display to be less annoying. However, driver trust and overall preference was highest for the multimodal display. Similar findings have been reported in other simulator studies (Scott & Gray, 2008). Likewise, a study of L2 vehicles found that drivers both reacted and took control of the vehicle faster when receiving multimodal (visual and haptic) alerts as compared to visual-only alerts (Blanco et al., 2015; see Chapter 2). Further research is needed to understand the implications of using haptic displays in automotive settings, especially in non-safety critical displays.

Design Issues

Most of the relevant literature (Kiefer et al., 1999; ISO [ISO/TR 16352}, 2005; Campbell, Richman, Carney, & Lee, 2004) suggests that operator performance can be improved by combining auditory and visual messages when presenting warnings. In addition to the above, Williges and Williges (1982) have pointed out another advantage of visual versus auditory presentation. That is, that a visual message can be referred to until it is understood and "encoded," not simply referred to again later to aid with memory; an auditory signal, in contrast, is heard once (typically), and if it is not comprehended at that time, there is not a second chance for encoding.

Cross References

Multimodal Messages, 4-8; Chapter 5: Visual Interfaces; Chapter 6: Auditory Interfaces; Chapter 7: Haptic Interfaces

Topic References

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Multimodal Messages

Introduction

A multimodal DVI consists of more than one type of signal from the visual, haptic, and auditory modalities and is quite suitable for delivering messages to drivers. This topic provides information on how to create multimodal driver messages.

Design Goal (L2, L3): Present simultaneous auditory, haptic, or visual signals that enhance driver messages and are quickly and reliably detected by the driver.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when: Safety-critical messages are multimodal (either bimodal or trimodal), and consist of an effective combination of auditory, haptic, or visual signals. Non-safety critical messages are presented in a multimodal fashion in order to increase the likelihood of the driver receiving the message. Multiple, simultaneously activated, signals are used to enhance temporal redundancy, maximizing the likelihood a driver will receive an alert (Fricke, 2007; Hecht & Reiner, 2009). If used as an alert, visual components of a multimodal message can persist beyond the duration of auditory or haptic signals to provide post-alert information regarding the nature of the alert (ISO, 2005). A sequential change in modality is used for different stages of a graded system—e.g., an early auditory tone alert to call driver attention to a less invasive signal like a visual display.

Example considerations for specific functions of different display types used for a multimodal display that deliver imminent warning messages.

Modality	Description
Visual Displays	**Head-up Display (HUD):** Used in conjunction with auditory or haptic alerts to encourage drivers to attend to the forward roadway in safety critical situations (Lind, 2007); safety concerns may arise if HUD images block the driver's view of forward hazards.
	High Head-down Display (HHDD): Used to improve noticeability of the visual aspects of a message for drivers who are unable to hear or feel the signals from the other modalities that are used (ISO, 2005).
	Low Head-down Display (LHDD): Used to present visual messages; these are paired with auditory or haptic signals (ISO, 2005). For safety critical messages, the presentation period may begin after the warning criterion is no longer exceeded, following an auditory or haptic signal (ISO, 2005).
	Instrument Panel (IP) Display: Used to present visual messages. However, the use of this space as part of a multimodal display for safety critical information is not recommended (Perez, Kiefer, Haskins, & Hankey, 2009; SAE J2400, 2003).
Auditory Displays	**Speech Messages:** Speech can also be used to supplement or more clearly indicate information provided in a visual or haptic display, such as providing messages or instruction to the driver.
	Simple Tones (Conventional Auditory): Simple tones are commonly paired with haptic and visual. Spatial messages using simple tones are enhanced greatly when coupled with spatial haptic messages (e.g., Fitch, Kiefer, Hankey, & Kleiner, 2007).
Haptic Displays	**Vibrotactile Seat:** Commonly paired with auditory or visual displays, e.g., the addition of audio or visual displays may facilitate driver comprehension of more complex vibrotactile seat displays.
	Other Haptic/Tactile Displays: May be implemented as part of a multimodal warning system. However, limited research is available regarding the use of seat belt pre-tensioning or brake pulses as a component of a multimodal display.

Discussion

Many vehicle displays are bimodal and can present both visual and auditory signals. A bimodal presentation scheme can be employed for in-vehicle tell-tale messages using a tone, to alert the driver to a system issue, coupled with a visual component (e.g., the tell-tale visual icon) to convey the nature of the system problem (ISO, 2005). The use of multimodal displays may also help ensure messages are delivered to drivers with unisensory deficits (e.g., older populations; see Laurienti, Burdette, Maldjian, & Wallace, 2006) or drivers who are not engaged with the driving task (e.g., distracted or operating in highly automated conditions).

Auditory and haptic signals are beneficial when used to deliver a message for a multimodal display because they are detectable even when drivers are glancing away from the roadway or information displays. A study comparing visual-only to combination visual and haptic messages in L2 vehicles demonstrated that drivers reacted and took control of the vehicle faster when receiving multimodal take control messages (Blanco et al., 2015, see Chapter 2). Visual messages can serve as "back-up" communication channels if there is high ambient noise/vibration or if a driver is hearing impaired, as well as a method for portraying the nature of the alert (ISO, 2005).

The reference to Fitch, Kiefer, Hankey, and Kleiner (2007) is included because their results were obtained using laboratory methods that have broader application. They investigated a multimodal presentation format for providing directional alerts for collision avoidance systems and had their participants simply indicate the direction participants' felt the interface was indicating.

Design Issues

Correspondence and Redundancy: Forming a full correspondence between stimuli across multiple modalities that are not normally associated with one another is unlikely to occur without significant training (Spence, Ngo, Lee, & Tan, 2010) or experience. Therefore, messages need to be intuitive and easily learned so that drivers can straightforwardly begin to integrate multimodal signals over time. For higher priority messages, early timing is recommended to give drivers adequate time for processing and responding to multimodal displays that deliver complex messages (e.g., spatial cues). Redundant temporal cues (e.g., simultaneous signals at the same time) may be adequate to pique the attention of a driver.

Cross References

Developing Driver Training Material for Automated Driving System Applications, 3-14

Topic References

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Chapter 5. Visual Interfaces

This chapter contains topics on visual displays. The visual modality is of primary importance in the driving task, and is amenable to the use of various sensory dimensions such as color, luminance and contrast, as well as stimulus dimensions such as location, size and shape and periodicity (e.g., flashing). Additionally, vision is the channel for presenting written information, and so is appropriate for messages from the vehicle automation involving semantic content that benefits from persistence, as distinct from auditory linguistic warnings, which tend to be obtrusive if they persist.

While vision provides a rich field for information coding and potentially complex messages that can help interpret messages provided by the DVI of automated driving systems, some challenges must be addressed in order to ensure their effectiveness. Visual warnings must be seen to be effective, and placing them in optimal locations in the cab can facilitate rapid detection of visual signals and promote faster responses to them. In addition, characteristics such as display type, color, size, spacing, and temporal characteristics (e.g., flashing or apparent motion) can be chosen to maximize the conspicuity, legibility, and comprehensibility of warning messages.

Glare from strong light sources presents another challenge to visibility, conspicuity, and legibility of warning messages. Effective warnings depend on the display having sufficient contrast that drivers can easily detect and read the images presented thereon. Glare on the display reduces the contrast of images presented on the display, while glare emanating from the display reduces contrast sensitivity in the eye. Both sources of glare can potentially reduce the effectiveness of warning displays by limiting the visibility of messages. This chapter discusses methods for mitigating glare, both on the display and from the display, in order to prevent loss of contrast.

Head-up displays have the potential to provide drivers with critical, forward-oriented information while minimizing glance times away from the forward roadway scene, potentially reducing eye movement and accommodation time. Images presented on the HUD, however, have the potential to be distracting and can partially occlude important visual cues outside the cab. Consequently, warning displays presented on HUDs should be designed with care. Nevertheless, the HUD can be an effective display for presenting time-critical messages.

Design topics addressed in this chapter:

- Locating a Visual Display
- Display Glare
- Head-Up Displays
- Using Color
- Selecting Character Height for Icons and Text
- Temporal Characteristics of Visual Displays

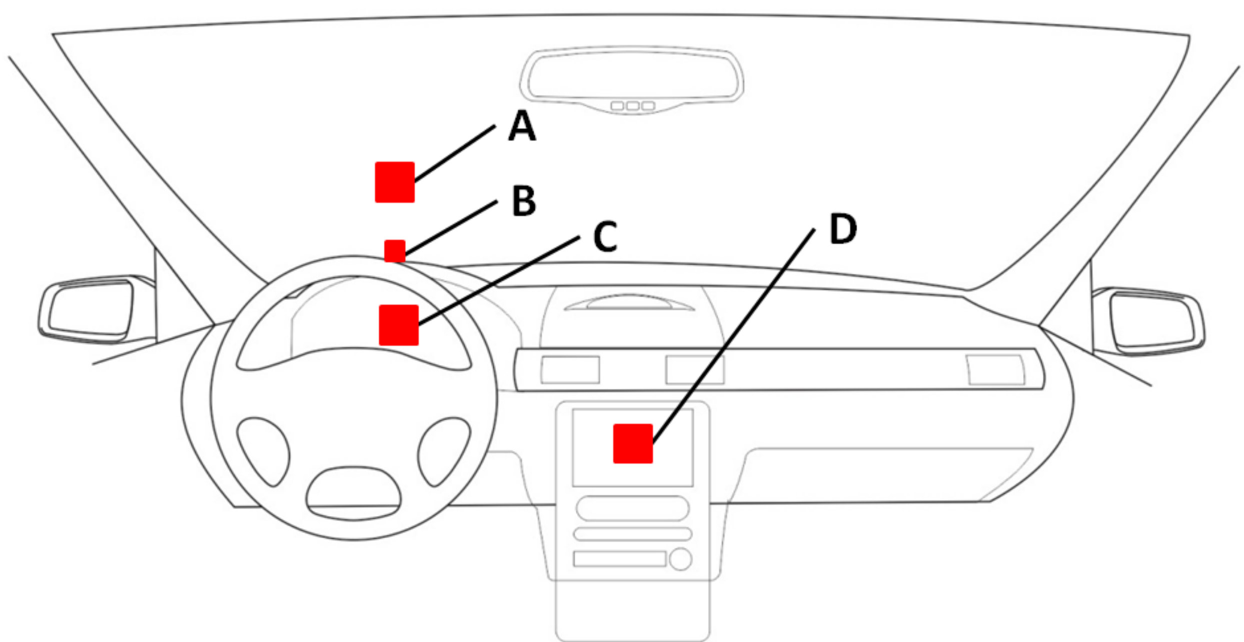
Locating a Visual Display

Introduction

The location of a visual display is a key factor affecting the ease with which drivers can obtain information. The placement of the visual component of a DVI will facilitate access to the information. The main focus of this topic is locations for visual displays, some attention is devoted to techniques to minimize glare for increased readability.

Design Goal (L2, L3): Place the visual interface in a location that facilitates rapid extraction of information while minimizing eyes-off-road glances and negative impacts on driving performance.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when: Critical displays for continuous vehicle control or critical warnings related to vehicle forward path are within ±15 degrees of the central line of sight but as close to the central line of sight as practicable. ISO (1984) recommends that messages that require immediate detection be located within 5 degrees of the forward view when possible. Displays are designed and located to minimize glare from external sources or other displays in the vehicle (e.g., in the instrument panel or under a protective cover.

Examples of potential visual display locations (indicated by red squares and callouts).



Display Locations in Image:

A. Head-Up Display
B. High Head-Down Display
C. Head-Down Display/Instrument Panel
D. Center Console

Discussion

In general, placing a visual display near the forward line of sight to the primary driving task may increase the likelihood that it will be seen, and will reduce the time needed to glance at that information, when drivers are looking out of the windscreen. The example display location of 15 degrees within the line of is taken from the ComSIS preliminary guidelines (Lerner, Kotwal, Lyons, & Gardner-Bonneau, 1996), but the relevance to L2 and L3 automated driving has yet to be validated. ISO (2005) recommends that visual displays intended to send critical messages to the driver be located as near to the driver's line of sight as possible, particularly if color is used. ISO (1984) recommends that critical visual messages that require immediate detection should be located within 5 degrees of the driver's line of sight.

Lind (2007) compared a collision warning HUD displayed in the central driver view in response to critical road hazards, with displays on the upper dashboard (HHDD), instrument cluster, and a steering wheel array of light emitting diodes (LEDs). This study involved a strictly visual HUD, i.e., there was no associated auditory cue. The salient attentional signal was flashing of the LED matrix (presenting at 4 Hz for 1.2 s). This type of HUD is different than more conventional implementations of HUDs, which may use alphanumerics, graphics or icons.

Design Issues

Although there is limited research on locations for L2 and L3 automated driving system messages exists, it can generally be assumed that drivers will expect key visual information to be presented in the general vicinity of the instrument panel. However, existing guidance is based upon the assumption that the driver is generally looking towards the forward roadway. L3 automated driving systems operate with the assumption that drivers will not be looking towards the road [5], and extended eyes off road time is possible in L2 operations. Further research is needed as to how drivers sample information from displays during both L2 and L3 automated driving.

Cross References

Multimodal Messages, 4-8

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Display Glare

Introduction

Glare on visual displays can originate from a variety of sources in the driving environment and can make visual displays difficult to read. In addition, light emanating from displays can be glaring at night causing discomfort, or in some conditions, reduced visibility of the external driving environment. This topic discusses ways to mitigate both the reduced legibility and conspicuity of display information due to glare on the display and the reduced visibility of the environment and increased physical discomfort caused by glare from in-vehicle displays.

Design Goal: Minimize glare, both on and from, visual displays.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met through the following strategies: Mitigating glare on the display in daytime driving: Provide sufficient display luminance and use high contrast display technologies to ensure adequate contrast. Place safety-critical displays in a location that minimizes exposure of the display sunlight. Use designs or locations that provide shading, such as a cowling or an inset bezel. Use anti-glare coatings or films to filter incoming light and reduce glaring reflections from the display. In some configurations, smaller display sizes can be easier to shade; however, care must be taken to ensure that other important design considerations, such as symbol size and conspicuity, are not compromised. Mitigating glare that emanates from the display while driving in darkness: Provide a control that allows drivers to adjust the display intensity but do not allow drivers to turn the display off completely. Use light sensors to automatically reduce display luminance in darkness. Display content using a dark background to minimize the luminance emanating from the display. Locate and orient the display to minimize reflections on windows. Consider locating non-safety-critical displays in highly eccentric locations relative to the forward gaze (e.g., center stack) to increase the glare angle. Do not use this approach for critical safety messages.

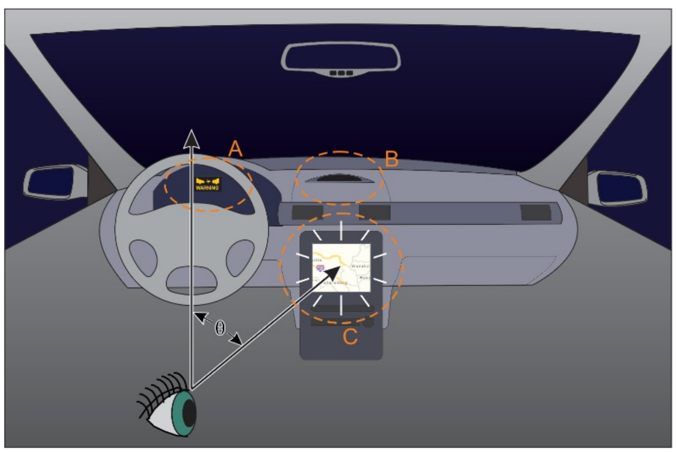
Examples of mitigations for glare incident on and emanating from the display.

Glare on the Display in Daylight

A. Display embedded in the instrument panel to protect from sunlight

B. Display mounted in recess above the center stack

A & B. Display luminance is sufficient to ensure adequate contrast



Glare from the Display in Darkness

C. Display intensity is adjustable to allow drivers to control amount of luminance

$$L_{veil} = I_{glare} \cdot \left(\frac{10}{\theta^3} + \left[\frac{5}{\theta^2}\right] \cdot \left[1 + \left(\frac{A}{62.5}\right)^4\right]\right)$$

Where
L_{veil} = veiling luminance
I_{glare} = luminous intensity of glare source
θ = glare angle
A = driver age

The CIE veiling luminance model to the left shows that veiling luminance (L_{veil}) increases as (1) glare intensity (I_{glare}) increases and (2) glare angle (θ) decreases. Increased veiling luminance results in reduced visibility

Adapted from (Vos, et al., 2002). Used with permission.

Discussion

Glare on the display: Intense light, such as sunlight, that falls on a visual display superimposes a uniform luminance onto the display, essentially "filling in" the darker areas of the displayed image, thereby reducing image contrast (i.e., the luminance ratio of the light to dark areas is reduced). The image on the display becomes increasingly difficult to read as the contrast decreases, until eventually the image can no longer be detected ((Vos, et al., 2002; Human Factors and Ergonomics Society, 2007). This reduction in contrast could be a particular problem for applications that rely on visual displays to present time-critical safety messages because lower contrast can increase drivers' reaction times or they may not see the display altogether.

Glare from the display: Glare from a visual display occurs when the intensity of the display within the visual field is substantially greater than the visual adaptation level, causing physical discomfort or pain (discomfort glare) and/or reduced visibility (disability glare). A portion of the light entering the eye is scattered in the transparent media of the eye (i.e., cornea, lens, and vitreous fluids) and by the tissues in the ocular fundus (Adrian & Bhanji, 1991). Some light also diffuses through the sclera and iris tissues. The scattered light superimposes a uniform veiling luminance onto the retinal image, reducing its overall contrast. If the contrast of the image falls below the contrast threshold for visibility under these conditions, it will be rendered invisible (Vos et al., 2002). Veiling luminance is influenced primarily by the intensity of light, the surface area of the lighted areas of the display, and the angle at which the glaring luminance enters the eye.

Design Issues

Glare on the display: Preventing glare from sunlight falling on an in-vehicle display can be extremely challenging to designers. Kiefer et al. (1999) recommend that one way to mitigate glare on a display is to provide sufficient luminance from the display in daytime driving to ensure adequate contrast. High-contrast display technologies can also reduce the effects of glare on the display. (Wreggit, Powell, Kirn, & Hayes, 2000) found that an electroluminescent display provided sufficient contrast for legibility, and drivers reported no washout or glare from sunlight. Because vehicles are not stationary, it may be difficult (or perhaps impossible) to locate a display in a location that will never receive direct sunlight. Nevertheless, placing the display in the instrument panel, in a custom recess, or within a shading bezel, etc., can help reduce exposure to glaring light. In some configurations, smaller displays may be easier to protect from direct light because they have less surface area to shade; however, it is important to ensure that other aspects of DVI design (e.g., text and icon legibility, conspicuity) are not compromised when using a smaller display.

Glare from the display: Several mathematical models have been developed that estimate the amount of veiling luminance developed by a glare source (e.g., Vos et al., 2002; Adrian & Bhanji, 1991; Farber & Matle, 1989). These models show that veiling luminance is directly proportional to intensity and inversely proportional to the angle at which glaring luminance enters the eye relative to the forward gaze. Thus, there are two primary solutions for reducing the effects of glare emanating from in-vehicle displays: (1) reduce the amount of light emanating from the display and/or (2) increase the eccentricity of the display location. A preferred approach for reducing the effects of glare from displays is to provide a control that is used to adjust the display intensity This can be a manually operated control that drivers manipulate or an automated control that adjusts display luminance based on sensors that detect ambient light levels. Regardless of how the control is implemented, however, the amount of control provided should be limited, however, to prevent drivers from turning off the display completely (Kiefer et al., 1999). Another way to reduce display luminance is to present content on a dark background in order to minimize the overall surface area of high-intensity portions of the image. Finally, locating the display further into peripheral vision can reduce the effects of glare, but with important tradeoffs with regard to reductions in warning conspicuity and detection.

Cross References

Locating a Visual Display, 5-2

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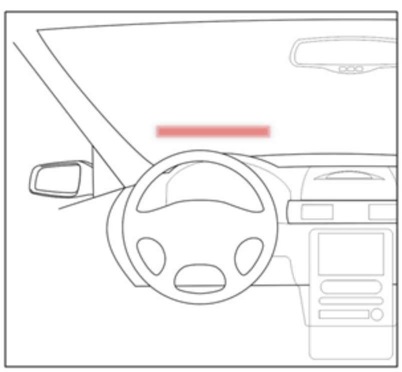
Head-Up Displays

Introduction

Head-up displays (HUDs) have the potential to provide drivers with critical information while minimizing glance times away from the forward roadway scene. This can increase the speed of information access by the driver by reducing eye movement and visual accommodation time. HUDs have been used and studied extensively in aviation (Prinzel & Risser, 2004) and, as costs have reduced, are being used more frequently in automobiles. HUDs also have the potential to expand display space within the vehicle. Application of the technology may proceed conservatively, however, while impacts of factors such as potential distractions and driver individual differences are further evaluated. Designers can consider the necessity of the information with regard to the current driving situation when deciding what information to provide via HUD. However, there exists a sufficient body of information on HUDs - both in aviation and, more recently, in automotive applications - to establish design guidance.

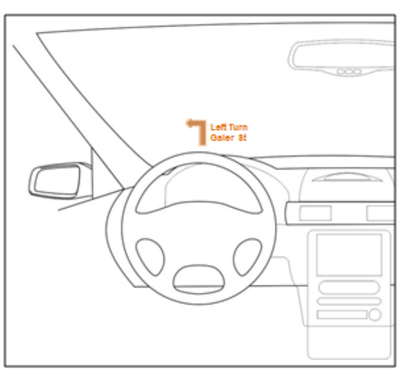
Design Goal (L2, L3): Use HUDs to present simple indications of critical safety situations in the driver's forward view.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when: Information presented via HUD is interpretable within the HUD and does not require visual reference to other head down displays. Information relevant to the driving situation is prioritized over presentation of non-driving related information. The use of continuously presented stable-value information on a HUD is minimized. The use of symbols, text, or indicators that continuously change in value is limited. The HUD is located 5 degrees to the right and 5 degrees below the center line of driver view.

Two potential uses and implementations of HUD displays.



HUD providing a warning.

- Only present during alert
- Used in conjunction with other modalities
- Removed after scenario resolved



HUD providing navigation information.

- Only provides driving/navigation relevant information
- Does not provide stable-value information (e.g., "Navigation Active")
- Minimal number of dynamic elements
- Driver may disable if desired

Discussion

While HUD use in L2 and L3 automation applications remains an unexplored topic from the standpoint of publically available literature, guidance from automotive HUD use in safety applications are useful. These principles are primarily applicable during L2 operations or when the driver's attention must be reoriented due to a pending transfer from automated to manual control.

HUDs have been studied in a number of different configurations and conditions, including comparisons with HHDDs, traditional instrument clusters, and under various traffic load, secondary task and hazard detection conditions. The clearest result to emerge from this work is the advantage of the HUD in reducing braking time and increasing warning detections for critical road events (Lind, 2007; Kieffer, 1996).

The balance of evidence suggests that under test conditions, HUDs or HHDDs (located slightly lower than HUDs, yet above the instrument cluster) tend to improve driver performance as measured by vehicle headway distance, response time to critical events, and other measures of driving behavior (Lind, 2007; (Charissis & Papanastasiou, 2010; Horrey, Wickens, & Alexander, 2003; Perez, Kiefer, Haskins, & Hankey, 2009).

Location of a HUD is the variable with the most consistent findings across a range of experiments, which suggest that the HUD should be located approximately 5 degrees to the right and 5 degrees below the driver's central visual focus (Yoo, Tsimhoni, Wantanabe, Green, & Shah, 1999). There is some evidence that display HUDs are preferred by drivers in simulator studies, and they yield better driving performance and information detection than a head-down display (HDD) (Charissis & Papanastasiou, 2010).

Design Issues

As a platform for safety-critical messages, HUDs are most appropriate for providing drivers with information relevant to the forward roadway or attracting the driver's attention during an automated to manual transition. This approach reserves the HUD location for critical information that is unlikely to be extraneous or distracting. The designer should carefully consider what information is presented in the HUD and only provide information that is relevant to the driver, minimizing presentation of non-driving related information. Presentation of stable-value information, especially when not directly related to the driving task, should be minimized. Likewise, dynamic elements that are not critical to the driving task or system status should not be incorporated.

Other approaches, such as providing vehicle or automation system status, are more complex and involve a much larger range of display elements and properties. While there seems to be no documented detrimental effect of these types of displays in laboratory and limited on-road testing for passenger vehicles, they may have the effect of reducing the impact or salience of critical forward warnings, or worse, lead to an excessively cluttered field of view.

Cross References

Display Glare, 5-4

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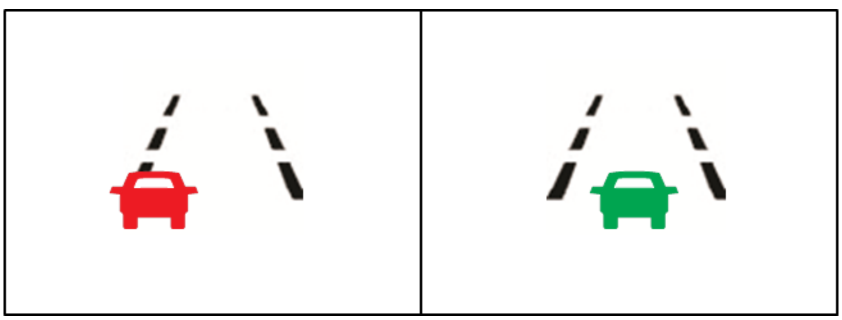
Using Color

Introduction

Color is a characteristic of visual displays that can be useful for conveying meaning or urgency of alerting signals. Color has certain advantages over text and symbols in terms of immediacy of recognition, and can serve to reinforce meaning conveyed by other methods. Color is a complex variable, however, and issues of luminance, hue, contrast and potential conflicts with other messages must be considered during design.

Design Goal: Use color to augment visual information presented in the displays to attract attention and/or to convey the urgency of conditions or situations.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when: The color is associated with the level of warning: – Red is normally associated with danger or critical situations – Yellow is normally associated with caution – Green is normally associated with normal operation; however, other considerations about warning conspicuity may necessitate using a different color (see Design Issues on the next page). The colors that are used are compatible with symbols based on prior association, such as red for octagonal stop signs, and yellow for triangular or diamond warnings. The quantity of colors used to code information is minimize; do not to exceed 4 color codes. Color is used to create a "pop-out" effect in forward collision warnings to show the area of concern more distinctly from the background scene. The following color contrast combinations are avoided: green/red, green/blue, yellow/red, yellow/blue, violet/red.

Example illustrating a potential use of color as part of a system status display.



This image shows a hypothetical lane centering status display. The left image indicates that the car is not centered in the lane. The non-centered status is provided through position of the car on the lane display, as well as through the red color of the car. The right image indicates that the car is centered in the lane. The centered status is portrayed through showing the car in the center of the lane display and through the green color of the car.

Discussion

The stereotyped interpretation of certain colors can be used in combination with other information to convey or provide messages to the driver, and, importantly, to promote appropriate and timely responses when compatible with stereotypical stimulus-response pairings. The traditional association of the color red with "danger or critical situation," yellow with "caution," and green with "normal" can be used to compliment auditory or haptic signals, and to convey urgency (ISO, 2005). While there have been some recent findings that the association of red with "danger" is stronger than the association of yellow with "caution" (Leonard, 1999), the context of driving would tend to reinforce the stereotype interpretation based on the frequency with which such colors are encountered in the roadway environment.

During development of the air bag warning label, NHTSA focus groups (49 C.F.R. pt. 571.208, 2011), did not associate orange with the word "danger." To reduce potential ambiguity, and to maximize perceived color distinctiveness, yellow should be used to indicate a discrete system warning or cautionary state (however, see Design Issues below). The color green should not be used to provide a warning to the driver because it is associated with safe or normal operating conditions (ISO, 2005).

Color and shape combinations are used for specific types of warnings and traffic regulation on road signs, and use of the same combinations for in-vehicle messages will help to maintain consistency between the road infrastructure and in-vehicle information environments. For example, use of a diamond shaped symbol with yellow background and black text is the accepted standard for warning signs (FHWA, 2012), and application of these conventions for specific automated driving system warning messages is appropriate. Color-shape combinations can increase reaction times when signs utilize shape as well as text because additional decision elements are used; thus if a shape is associated with a highly stereotyped response, additional text may lead to longer reaction times (Tijus, Barcenilla, Cambon de Lavalette, & Maunier, 2007).. Designers should avoid incompatible or unconventional shape and color combinations, such as octagonal shape (conventional meaning = stop) presented with a yellow background (conventional meaning = caution).

Color contrast can affect the perception of both the background and message content through complex interactions of luminance and visual system effects. Avoidance of the specific combinations described in the Design Guidance above will preclude this problem (ISO, 2005). For messages requiring the presentation of text, green text has the advantage of being at the frequency of maximum spectral sensitivity of the eye (NASA, n.d.). Similarly, green-yellow text (534 nm) best accommodates both light- or dark-adapted eyes.

Design Issues

Color should not be used as the primary or exclusive means by which information is conveyed, but instead a supplementary element or alternative cue to meaning. When approached in this way, designers can think of appropriate location and symbol-shape means to convey the principal message content, and color can be used as a means to more quickly draw attention and reinforce meaning through traditional associations. Furthermore, relying on characteristics other than color will convey to drivers with color-blindness important information that might otherwise be missed if color were used exclusively to communicate the information.

Keeping the number of color codes within human cognitive limits is important in the driving environment. Four colors is the recommended maximum, as this corresponds generally to the warning levels of danger, warning, caution and normal operation (ISO, 2005).

Cross References
Designing Messages for Driver Comprehension, 4-2; Locating a Visual Display, 5-2

Topic References

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Selecting Character Height for Icons and Text

Introduction

Optimum text and graphic symbols presented in the driver-vehicle interface are legible under a large range of viewing distances, viewing angles, and environmental conditions. Legibility goes beyond visibility or detection; it implies being able to discern shape or character identity based on appearance. An important factor that influences legibility of an icon is the size of the symbols that comprise the icon—both graphical symbols and text. This topic addresses symbol size, which refers to the visual angles subtended by the icon, its graphical elements, text within the icon, and free-standing text.

Design Goal (L2, L3): Select sizes for text and icons that support rapid message legibility.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when: **Icon Size:** Optimal visual angle of primary graphical elements[1]:86 arcminutes Minimum visual angle of primary graphical elements[1]:41 arcminutes for time-critical applications 34 arcminutes for non-time-critical applications **Text Size (both within the icon and free-standing text—see the discussion):** Optimal height:20 arcminutes Minimum height:16 arcminutes for time-critical applications 12 arcminutes for non-time-critical applications [1] Primary graphical elements provide the primary information needed to encode or detect the icon. Secondary graphical elements provide additional context or clarifying information. Optimum visual angle refers to the angle at which the primary graphical elements are both conspicuous and legible. Minimum visual angle refers to the smallest angle at which the primary graphical elements are legible but not necessarily conspicuous [2].

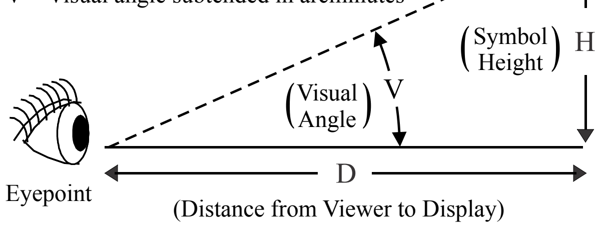
The table below provides equations for calculating the sizes of the icon, its graphical elements, text within the icon, and free-standing text. Note that the equations assume the visual angle is measured in arcminutes, symbol height is in millimeters, viewing distance is in meters, and the trigonometric functions (tangent and arctangent) accept and return values in degrees rather than in radians. Appropriate conversion factors must be applied for different units.

Equations for calculating symbol height, visual angle, and viewing distance.

If Known…	Use These Equations for Calculating These Unknowns		
	Visual Angle (V) in arcminutes	**Symbol Height (H) in millimeters**	**Viewing Distance (D) in meters**
Viewing Distance (D) and Symbol Height (H)	$V = 60 \cdot \text{Arctan}\left(\frac{H}{1000 \cdot D}\right)$	—	—
Viewing Distance (D) and Visual Angle (V)	—	$H = 1000 \cdot D \cdot \text{Tan}\left(\frac{V}{60}\right)$	—
Visual Angle (V) and Symbol Height (H)	—	—	$D = \frac{H}{1000 \cdot \text{Tan}\left(\frac{V}{60}\right)}$

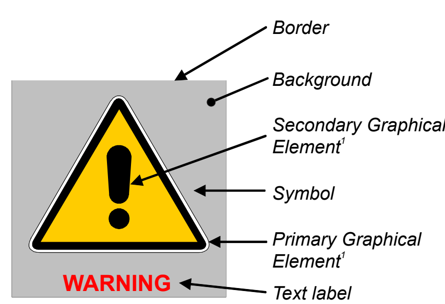
Definitions of Variables Used in the Equations

H = Symbol height in millimeters
D = Viewing distance in meters (0.5–1.1 m)
V = Visual angle subtended in arcminutes



Figures adapted from Campbell et al. (2007)

Examples of Symbol Elements in an Icon



Discussion

Icon size: The design guidance above for icon size are consistent with the recommendations made by ISO/TR7239 (ISO, 1984), which were based on a variety of research related to detection and resolution thresholds. The optimum visual angle suggested (86 arcminutes) is aimed at ensuring conspicuity, while the minimum visual angle (41 arcminutes) simply ensures legibility. It is important to note that the recommendations made by ISO (1984)—and therefore the supporting design guidance on the previous page—are based on the assumption that the icon will not be placed outside a 15-degree angular displacement from the central line of the normal direction of user's vision. ISO (1988) specifies that the minimum size of graphical symbols for use on equipment should be 1/100th their viewing distance, which corresponds to 34 arcminutes of visual angle. The larger sizes in ISO (1984) are recommended for time-critical applications in order to ensure both conspicuity and legibility in the driving environment.

Text size: ISO 15008 (ISO, 2009) recommends that character heights for in-vehicle display text should subtend at least 20 arcminutes of visual angle, but 16 arcminutes is acceptable. Furthermore, the minimum visual angle for text should be no less than 12 arcminutes, but text of this size should be reserved for situations with only modest requirements for reading speed and accuracy. More recent research by O'Day and Tijerina (2011) verifies these values. They found that the highest accurate reading rate occurred with the largest text height they tested (20 arcminutes) and the lowest accurate reading rate for text that subtended 12 arcminutes. In addition, the greatest variability in accurate reading rate was associated with the smallest text. Taken as a whole, ANSI (HFES, 2007), Mourant and Langolf (2007), Howell and Kraft (1959), and Giddings (1972) agree with the ISO (2009) standard, recommending a minimum character height of 16 arcminutes and optimal character heights for high legibility in the range of 20 to 30 arcminutes. The recommendation given in this design principle reflects the specifications for text height found in ISO (2009) because it is an international standard that applies directly to the presentation of textual information in vehicle-based applications.

It should be noted that the literature did not provide any information that suggested the size of text within an icon should be different than the size of free-standing text in terms of legibility. Therefore, the design principle above does not differentiate between these implementations.

Design Issues

The size of in-vehicle displays is often limited by the available real-estate in the cab, which in turn limits the size of the symbols presented on the displays. This limitation can result in a tradeoff between symbol size and legibility. When designing in-vehicle displays, it is important to consider legibility when determining the sizes of symbols, especially in safety-critical applications where the time available to read and interpret the symbols is limited. O'Day and Tijerina (2011) found that a wide variety of character heights can be legible if the character width and stroke width are carefully chosen. Nevertheless, size is only one of the characteristics of graphical and textual symbols that affect legibility. The legibility of icons and text is determined by factors such as the size, stroke width, contrast, and luminance (Howell and Kraft, 1959; Carney, Campbell, & Mitchell, 1998).

Cross References

Using Color, 5-8

Topic References

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Temporal Characteristics of Visual Displays

Introduction

The temporal characteristics of visual messages can involve the use of flashing, blinking and motion in order to draw attention toward a particular visual display. The use of temporal characteristics, such as flash and motion, takes advantage of features of the human visual system that are especially sensitive to these features. This topic covers the design of in-vehicle messages that use temporal and movement features.

Design Goal (L2, L3): Use changes in the temporal characteristics of visual displays, such as flashing, blinking or apparent motion, to command visual attention.

Supporting Design Guidance

The best available research on this topic suggests that this design goal can be met when:

Flashing is used for important, suddenly-occurring, situations (optimal rate is 3-4 times/s).

Multiple flash mode is used for more urgent situations (this mode uses rapid pulses of flash for each flash cycle).

Flash rate and duty cycle (on-off period) are adjusted as needed to ensure driver comprehension.

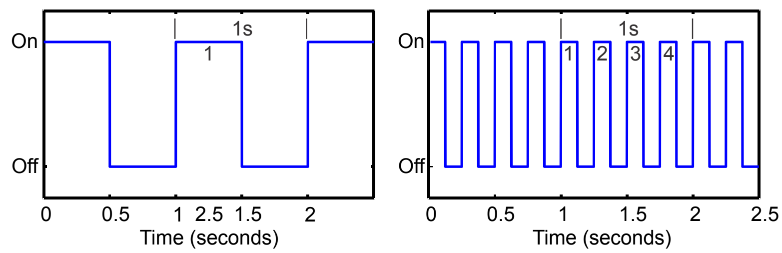
Sequential illumination is used to convey motion and/or direction, but keep text stationary.

Other motion cues such as bouncing or zooming are discouraged while in manual driving or during transitions to or from automated driving because they may unnecessarily increase driver eyes-off-road time.

Examples of flash rate and duty cycle.

Flash Rate (Frequency): The number of flashes per second. Example (a) shows lower flash rate (one flash per second), and example (b) shows higher flash rate (four flashes per second).

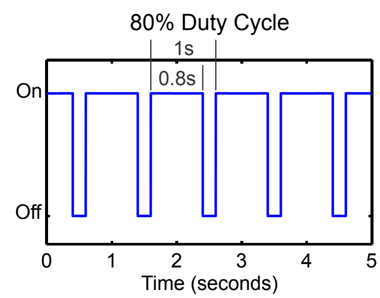
A high flash rate can be used to convey high urgency.



a) Low Frequency b) High Frequency

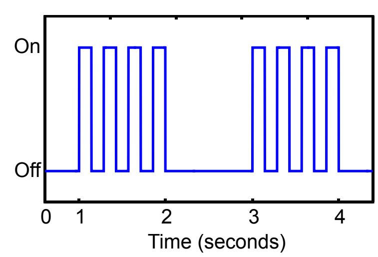
Duty Cycle: The percent of time within a cycle that the sign is in the “on” state. The example shows a signal with 80% duty cycle (“on” for 0.8s and “off” for 0.2s).

A higher duty cycle can be used for presenting icons with accompanying text in order to provide sufficient time for the driver to read the text.



Complex Flash: Presentation of multiple flashes with varying “on” and “off” times. The example shows two one-second bursts with four pulses per burst. Each burst is separated by one second of “off” time.

Complex flashes can be used to further increase perception of urgency.



Discussion

Use of flashing signals is a standard practice in warning system design (ISO, 2005). Much of this basic guidance may be useful for the construction of DVIs for L2 and L3 automated driving systems. The basic parameters of a flashing warning are the frequency, contrast, and duty cycle. Frequency refers to the number of times per second the signal flashes; a considerable amount of human factors research suggests that for conveying urgency, an optimal flash rate is 3-4 times per second (ISO, 2005; Chan & Ng, 2009). It is possible also to modulate each flash within a cycle via a multiple "fast flash" mode—this has been found to further increase perception of urgency (Chan & Ng, 2009). Contrast refers to the change in illumination between the "on" and "off" portions of the flash. The duty cycle of the flash period refers to the relative amount of "on" and "off" time for the flashing signal—this is a relevant parameter if symbolic and verbal information are conveyed on a flashing warning because drivers require sufficient "on" time to view the information.

Sequential illumination of display elements can be used to create apparent motion, which can convey directional information pertinent to warning systems. ISO (2005) provides examples of movement in association with icons to convey dangerous situations such as emergency vehicles, icy roadways, etc. Motion should only be applied to icons or symbols; text should be stationary to reduce potential distraction or implied meaning associated with text motion.

Motion cues may affect cognitive load. (Doshi, Cheng, and Trivedi (2009) used a number of motion cues in a HUD, including bouncing triangular warning signs, zooming warning signs and moving graphical indicators with a bounce to show excessive speed. The results suggested that motion without contextual information about speed led drivers to spend more time looking down at the instrument cluster to determine why the alert was being provided than they did with no alert.

Design Issues

Flashing and motion can be compelling visual display elements and are appropriate for use in higher priority situations if the message can be provided in appropriate temporal relationship to the message cause so that nuisance alarms are not perceived. The increasing ease of presenting visual effects such as zooming and bouncing of visual elements lead to an expanded interpretation of the "flash" concept. Type of motion, however, should not be used as a code in and of itself; instead, supplementary information should be provided (such as current speed or speed limit), without requiring the driver to visually refer to other instruments or displays.

Cross References

Multimodal Messages, 4-8; Locating a Visual Display, 5-2; Display Glare, 5-4

Topic References

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Chapter 6. Auditory Interfaces

This chapter provides guidance for the design of auditory interfaces. Auditory interfaces are useful for capturing and directing drivers' attention and for presenting information to drivers when they are not attending to a visual display. Consequently, these interfaces are particularly useful for presenting time-sensitive messages to drivers. Auditory signals can be used to convey three forms of information (Catchpole, McKeown, & Withington, 2004). First, urgency cues provide information regarding the criticality of the situation or how quickly drivers need to respond to the warning. Second, location information identifies where the hazard is located or where it is coming from. Third, the semantic meaning associated with the signal provides information to the driver about what is happening or what actions to take in order to avoid a crash. Even though all three forms of information do not necessarily need to be included in a single message, each of these components can provide useful information for facilitating rapid and correct responses.

As drivers of L2, and especially L3, automated driving systems may be engaged in non-driving related tasks, it cannot be assumed that the driver's visual attention will be directed towards the roadway. Auditory signals can be effective for presenting information to the driver because they can be perceived regardless of the direction of visual attention. These signals can be very effective in when they are salient, appropriately obtrusive, and their meaning can be understood. Various characteristics of auditory messages can be modulated to affect the level of salience and obtrusiveness as well as the perception of urgency, and the type of signal used can facilitate comprehension of the information being displayed.

There are design tradeoffs, however, that need to be considered in order to avoid unwanted side effects and ensure the message has its intended effect. Salient, obtrusive sounds can be annoying if they are presented often, too loudly, or if their characteristics are perceived as annoying. Yet sounds that are not obtrusive or loud enough may go unnoticed. Also, the meaning of some auditory signals, such as speech messages and auditory icons (auditory signals that sound like a real object or event, such as a screeching tire), can be easy to understand, while the meaning of other types of sounds, such as pure tones, must be learned.

The following topics are included in this chapter.

- Perceived Urgency of Auditory Warnings
- Perceived Annoyance of Auditory Warnings
- Loudness of Auditory Warning Signals

Perceived Urgency of Auditory Warnings

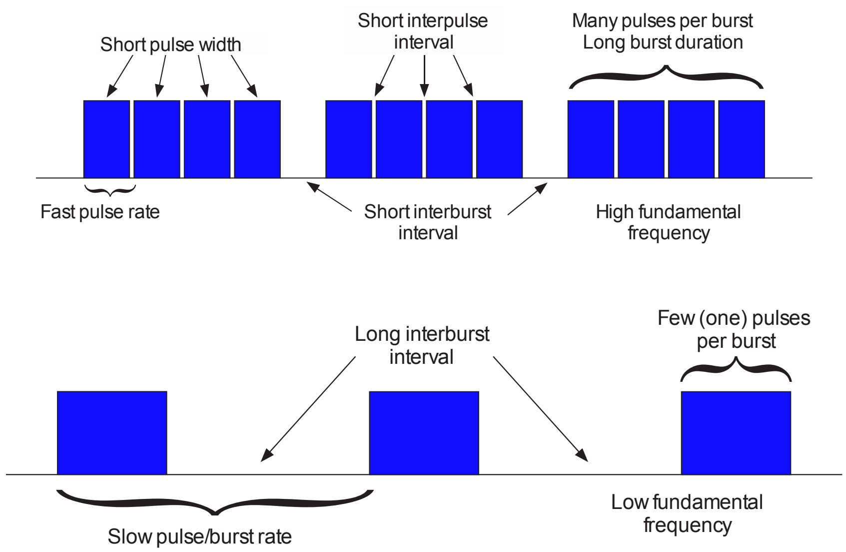
Introduction

This topic provides information for designing auditory warning messages that convey a level of urgency that matches the urgency of the hazard situation.

Design Goal (L2, L3): Use an auditory warning to clearly communicate a level of urgency consistent with the urgency of the task, event, or situation.
Supporting Design Guidance
The literature suggests that the attributes listed below may be manipulated in support of the design goal. Note that this list is not intended to be comprehensive.

To increase the perceived urgency:	**To decrease the perceived urgency:**
Use faster auditory signals (e.g., 6 pulse/s).	Use slower auditory signals (e.g., 1.5 pulse/s).
Use regular rhythms (all pulses equally spaced).	Use irregular rhythms (pulses not equally spaced).
Use a greater number of pulse burst units (e.g., 4 units).	Use a fewer number of pulse burst units (e.g., 1 unit).
Use auditory signals that speed up.	Use auditory signals that slow down.
Use high fundamental frequencies (e.g., 1000 Hz).	Use low fundamental frequencies (e.g., 200 Hz).
Use random or irregular overtones.	Use a regular harmonic series.
Use a large pitch range (e.g., 9 semitones).	Use a small pitch range (3 semitones).
Use a random pitch contour.	Use a down or up pitch contour.
Use an atonal musical structure (random sequence of pulses).	Use a resolved musical structure (from natural scales).
Use more urgent words (e.g., “Danger”).	Use less urgent words (e.g., “Caution”).

Examples of auditory signals (tones) with urgent (top) and less urgent (bottom) characteristics.



Discussion

Varying certain acoustical properties has a strong and consistent effect on a person's subjective impression of the urgency of an auditory warning. Accurate portrayal of urgency helps drivers to understand the warning and respond more effectively. Scaling of the urgency of the warning must be selected with understanding the potential for the driver to be engaged in a non-driving related task, possibly for an extended period of time prior to warning issuance. In general, greater perceived urgency of a warning is associated with faster reaction times (Campbell, Richman, Carney, & Lee, 2004; Suied, Susini, & McAdams, 2008) however, signals that are perceived as more urgent than is warranted by the situation can result in confusion, distraction, or inappropriate responses, such as overly aggressive responses. If auditory signals are designed with the proper level of urgency in mind, more effective warnings can be developed.

Design Issues

Signal attributes that can provide urgency cues include time-varying characteristics, frequency characteristics, and signal complexity (Campbell, Richman, Carney, & Lee, 2004; Suied, Susini, & McAdams, 2008; Department of Defense, 2012; Pomerleau et al., 1999; Tan & Lerner, 1995; Marshall, Lee, & Austria, 2007). Some specific characteristics that affect urgency are pulse rate, fundamental frequency, harmonic content, and (potentially) intensity. Several studies and guideline documents (e.g., Campbell, Richman, Carney, & Lee, 2004; Suied, Susini, & McAdams, 2008, (Gonzalez, Lewis, Roberts, Pratt, & Baldwin, 2012, 2007) suggest that increasing the pulse rate can increase perceived urgency; similarly, increasing the fundamental frequency also increases urgency. Furthermore, Edworthy, Loxley, & Dennis (1991) found that signals with irregular overtones increased perceived urgency, while those with regular harmonics decreased urgency. Some studies and guidelines (e.g., MIL-STD-1472G [Department of Defense, 2012], Pomerleau et al., 1999; Tan & Lerner, 1995) suggest that increasing the intensity (volume) increases the level of perceived urgency; however, intensity as an urgency cue should be used with caution. Although intensity can affect perceived urgency, it is not always clearly the case—at least one source (Lee, McGehee, Brown, & Reyes, 2002). showed that increasing the intensity as a means of presenting higher levels of urgency did not have a significant effect on the performance of the forward crash warning (FCW). More importantly, high-intensity auditory signals can be perceived as annoying, which can negatively impact driver performance as well as acceptability (Wiese & Lee, 2004).

Message semantics can also influence the perceived urgency of an auditory warning. A laboratory study (Guilluame, Drake, Rivenez, Pellieux, & Chastres, 2002). found that familiar, real alarms used in military aircraft were rated with different levels of urgency than their synthesized counterparts that had similar acoustic characteristics, suggesting that the mental representation of the sequence interacts with the acoustic properties in the perception of urgency. Similarly, the semantic content of speech messages has been shown to interact with loudness in simulated driving (Baldwin &., & May, 2011). The fewest crashes occurred when drivers received collision warning messages that included either the low-urgency word "Caution" presented at high intensity or the high-urgency word "Danger" presented at low intensity, while the most crashes occurred when the word "Danger" was presented at high intensity. These findings suggest that overall perceived urgency can be elevated without substantially increasing the annoying effects associated with high-urgency acoustic properties by incorporating high-urgency semantics (whether with speech or with familiar non-speech signals) into auditory messages that have lower-urgency acoustic characteristics.

Cross References

Perceived Annoyance of Auditory Warnings, 6-4

Topic References

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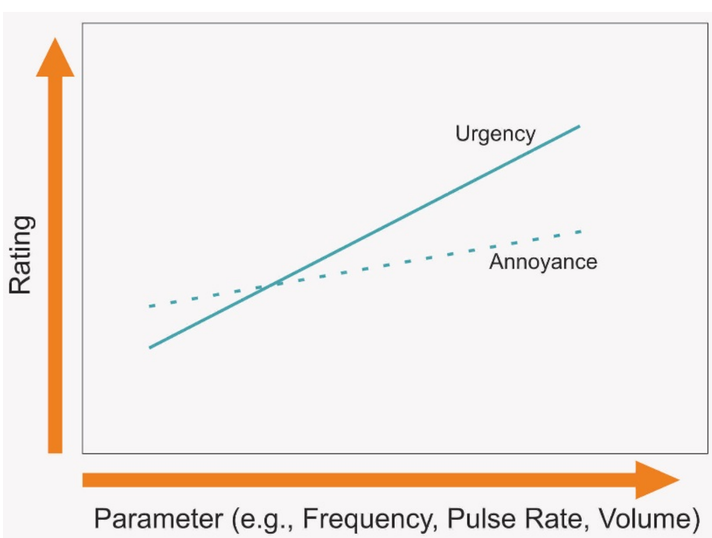
Perceived Annoyance of Auditory Warnings

Introduction

This topic provides information for designing auditory warning messages that are less likely to annoy drivers yet still convey an appropriate level of urgency. Urgent sounds often have characteristics that can also be perceived as annoying. Note that the presentation of other auditory information to the driver (e.g., navigation updates) is not covered by this topic.

Design Goal (L2, L3): Select auditory warnings that minimally annoy drivers.*
Design Guidance
The best available research on this topic suggests that this design goal can be met when: The perceived urgency of a sound is matched with the urgency of its referent. Drivers who perceive the benefits of an obtrusive signal will be less likely to be annoyed by it. Low annoyance sounds are used for benign situations. Minimize the rate of false or nuisance alarms to reduce the potential for annoyance. Repetitious Speech-based warnings are minimally repeated and no more than three times per crash avoidance situation, and in immediate succession. Systems use sounds with characteristics that promote perceived urgency more than perceived annoyance. *This topic does not apply to auditory warnings that are <u>intended</u> to annoy drivers, e.g., seat belt reminder.

Example of one analytical method for estimating the effect on perceived urgency and annoyance by varying sound parameters.



The figure on the left illustrates the relationship between urgency and annoyance when varying a signal characteristic, such as frequency, pulse rate, or volume, of an example auditory warning.

The graph shows linear regressions of subjective ratings of urgency and annoyance as described in (Gonzalez, Lewis, Roberts, Pratt, & Baldwin, 2012).

In this example, the greater slope of the urgency line indicates that urgency increases more than annoyance does when the parameter is increased.

This graph suggests that, for the particular auditory warning tested, the parameter under test should be increased to convey higher urgency because it has less impact on annoyance than on urgency.

Discussion

An important tradeoff exists between alerting and annoying when using auditory warnings. Highly urgent signals can also be perceived as annoying, and while many sound parameters that increase urgency also increase annoyance, careful design can create highly urgent sounds that are not overly annoying. The goal is to minimize the annoyance associated with a warning, balanced by the need to match the urgency of the signal to the urgency of the situation. This is called "annoyance tradeoff" and should be considered in signal design.

Auditory signals that are perceived to be annoying can increase workload (Wiese & Lee, 2004), be distracting, or cause the driver to disable the warnings altogether. This problem may potentially be compounded when more than one safety application, each with its attendant warning, is available in the vehicle. Consequently, designers should consider the potential for "alarm fatigue" when designing systems with multiple auditory warnings, even when the individual warnings are designed to minimize annoyance. General Motors Corporation and Delphi-Delco Electronic Systems (2002) found that forward crash waring (FCW) systems that produce a high number of false alarms can be considered annoying by drivers, even when the tone is appropriate for a system with a low number of false alarms. Similarly, although participants in one study (Kiefer, Cassar, Flannagan, Jerome, & Palmer, 2005) considered the auditory tone to convey the right level of urgency, more than half indicated they would turn off the alert suggesting that the sound was annoying.

Design Issues

Some sources (Campbell, Richman, Carney, & Lee, 2004; Marshall, Lee, & Austria, 2007; Hellier & Edworthy, 1989) indicate that certain quantifiable sound parameters such as inter-pulse interval (time between pulses), number of repetitions, duty cycle, and frequency have a greater effect on urgency than on annoyance. Other studies (Wiese & Lee, 2004; Gonzalez, Lewis, Roberts, Pratt, & Baldwin, 2012), however, found that increasing signal intensity, frequency, or duty cycle increased annoyance more than urgency. Results from (Gonzalez, Lewis, Roberts, Pratt, & Baldwin, 2012) suggest that if a signal parameter's psychophysical relationship with urgency is not stronger than its relationship with annoyance, it is likely not a viable parameter. The figure on the previous page demonstrates a method for quantifying the level of annoyance or urgency as a means of determining the relationship between urgency, annoyance, and the signal characteristics.

While this guidance applies to warnings, many of the concepts may be applied to the design of non-warning information for the driver of L2 or L3 automated driving systems. For instance, avoiding unnecessary repetition of a message, and careful selection of sound characteristics can lessen the potential for driver annoyance due to system messages. However, some uncertainty remains about the specific characteristics that a driver will find annoying in either the L2 or L3 automated driving environment. Also at issue is the fact that, especially in L3 operations, it will not be possible to know what the driver is doing. Drivers who are monitoring the road may find an alert annoying, whereas a driver engaged in some non-driving task may find the same alert helpful.

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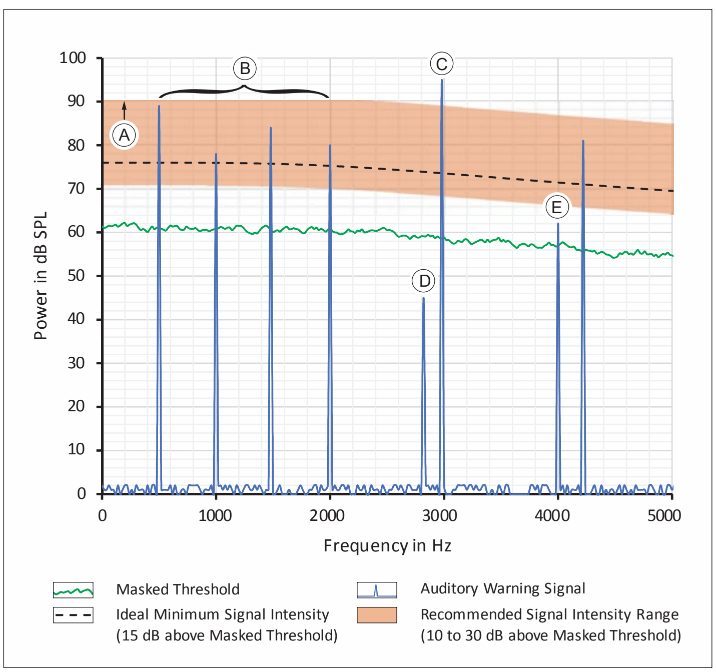
Loudness of Auditory Warning Signals

Introduction

This topic provides guidance and information regarding the intensity levels for presenting auditory warnings that are clearly perceivable. In order to be effective, auditory warnings must be loud enough to be heard in the noisy driving environment. The information below may assist designers in determining appropriate volume levels for presenting clearly audible warnings to drivers.

Design Goal (L2, L3): Select auditory warning signals that are loud enough to overcome masking sounds from road noise, the cab environment, and other equipment.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when: The amplitude of auditory signals is in the range of 10-30 dB above the masked threshold (MT), with a recommended minimum level of 15 dB above the MT. Alternatively, the signal is at least 15 dB above the ambient noise. The signal does not exceed a maximum intensity of 90 dBA. Designers avoid presenting auditory warnings at more than 30 dBA above the MT to avoid startling or annoying drivers. The auditory warning signal includes frequency components in the range of 500-2500 Hz, and the signal includes at least two dominant components in the subset range of 500-1500 Hz. The intensity of cautionary warning signals is less than the intensity of the imminent collision warning signals; however, if doing so will limit the ability of drivers to perceive the cautionary warning, other signal characteristics could be used to convey lower urgency. Other sounds produced by the vehicle (e.g., radio or HVAC fans) are muted or disabled while the warnings are presented, to enhance the audibility of warnings.

Relationship between masked threshold and recommended signal intensity range.



This graph shows the frequency domain of a hypothetical warning signal superimposed on the MT for noise conditions while driving[1].

A. Signal limited to 90 dB above the MT

B. Dominant frequency components in 500−2500 Hz range with two in the 500−1500 Hz range

C. Signal has potential to be startling or annoying because 3 kHz component is greater than 30 dB above MT

D. Frequency component will likely not be heard

E. Frequency component may not be perceived by some

Adapted from Edworthy & Hellier (2000).

[1] This graph shows a hypothetical scenario for illustrative purposes only. The signal itself is likely to be annoying, and the noise spectrum may not represent noise in real driving conditions.

Discussion

Little published research examining the loudness of warning messages for automated driving systems is available. The guidance listed here are based on research examining imminent collision warnings (ICWs) and cautionary collision warnings (CCWs) and should be generally applicable to presenting urgent (e.g., take control now) and cautionary (e.g., take control soon) messages in L2 and L3 automated driving systems. Additionally, standards on the maximum presentation limits of ICWs in an automobile (ISO 7731, 2003) are applicable in this setting.

In order for an auditory warning to be clearly perceived, it must be presented at an intensity that is substantially greater than the MT. The MT represents the minimum intensity level at which a sound presented among masking "background" noises is audible to a listener. It is important to note that the MT is not necessarily the same as the ambient noise level, and several factors influence the MT.

Two sources (Lerner, Kotwal, Lyons, & Gardner-Bonneau, 1996); Campbell, Richman, Carney, & Lee, 2004) recommend the warning intensity should be at least 20 dB and no more than 30 dB above the MT; however, other sources (ISO, 2005; Lee et al., 2004) indicate that drivers can discern auditory warnings at as little as 10 dB above the MT, and they recommend that auditory ICWs should be 10–15 dB above the MT in order for the warning to be reliably detected. Furthermore, the standards in MIL-STD-1472G (Department of Defense, 2012) require that caution signals exceed the ambient noise environment by at least 15 dB and that alerting signals exceed ambient noise by at least 20 dB. An ISO standard (ISO 7731, 2003) regarding danger signals in workplaces requires that at least one of the following criteria are met in order for non-speech signals to be clearly audible: (1) the A-weighted sound pressure level (SPL) of the signal must exceed the SPL of the ambient noise by more than 15 dB, (2) the SPL level must exceed the MT by at least 10 dB in at least one octave band, or (3) the SPL must exceed the MT by at least 13 dB in at least one 1/3-octave band. Most sources agree that the amplitude of auditory signals for ICWs should not exceed the MT by more than 30 dB in order to avoid startling or annoying the driver. In any case, the maximum amplitude of the warning should be limited. For auditory warnings in workplaces, ISO (2005) recommends a limit of 90 dBA.

Design Issues

Meeting these criteria can be challenging in noisy driving environments. If the MT in the vehicle is more than 75 dBA, the warning sound cannot meet the recommended 15 dB above the MT without violating the 90 dBA limit. One strategy for improving audibility of auditory warnings is to mute in-vehicle systems that generate competing auditory information or noise (e.g., stereo system or fans) (Kieffer et al., 1999) during warning presentation. Also, auditory signals comprised of multiple frequencies will increase the likelihood that at least one frequency will be detected. The ISO standard (ISO 7731, 2003) requires that the signal include frequency components in the range of 500-2500 Hz, and they recommended that there be two dominant components in the range of 500-1500 Hz. Frequencies in this range fall within the range of hearing that is most sensitive in humans and are most likely to be detected.

Lee et al. (2004) and Campbell, Bittner, Lloyd, Mitchell, and Everson (1997) recommend that the intensity of cautionary crash warning (CCW signals should be less than the intensity of ICW signals in order to communicate a lower level of urgency. Nevertheless, auditory CCWs should follow the same topics for minimum and maximum intensity as the auditory ICW to ensure that the warning can be detected above other auditory signals in the vehicle without being annoying or harmful. Signal characteristics other than intensity can be used to convey lower urgency if lower intensity signals cannot be reliably detected (see 7-4).

Cross References

Perceived Urgency of Auditory Warnings, 6-2

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Chapter 7. Haptic Interfaces

This chapter contains human factors design guidance on the use of haptic interfaces. There are two types of haptic interfaces that are discussed in this chapter: *vibrotactile* and *kinesthetic*. Although a full understanding of haptics is not necessary to use the guidance and topics in this chapter, it will be valuable for users of this document to understand that vibrotactile and kinesthetic interfaces have fundamental differences that impact how well drivers detect and understand haptic messages.

Vibrotactile interfaces provide information to the driver using vibrations. Vibrotactile interfaces need to be in physical contact with the driver to deliver information and, for L2 and L3 vehicles where the driver is not contacting the pedals or steering wheel during automated driving, likely work well when included in seat belts or the seats. The term vibrotactile is a combination of two words, vibration and tactile. The word tactile is used to describe perception of being touched. Tactile perception is a passive sense as tactile sensations are not necessarily associated with body movements. This is a defining characteristic between vibrotactile interfaces and kinesthetic interfaces and it has implications for detectability and understanding. Vibrotactile interfaces are often used to deliver information that is abstract from haptic signal. In general, people can sense when (e.g., temporal cue) and where on the body vibrations occur.

Kinesthetic interfaces provide information by causing limb or body motion. An example of this type of interface is when brake pulse displays cause a sudden jerk motion of the vehicle, causing the driver's body to move. The word kinesthetic is used in relation to the ability to sense static and dynamic body posture (e.g., knowing where your hands are located). Some kinesthetic display types may help enhance awareness (e.g., vehicle brake pulses alert drivers by causing entire body motions).

Vibrotactile and kinesthetic interfaces for automated driving systems are discussed throughout this chapter. The topics addressed in this chapter include:

- Selecting a Haptic Display
- Improving Distinctiveness of Haptic Displays
- Accommodating for Vibrotactile Sensitivity Across the Body
- Generating a Detectable Signal in a Vibrotactile Seat

Selecting a Haptic Display

Introduction

This topic provides information about different types of haptic displays, high-level descriptions, and their potential uses for safety-critical messages. The additional topics in this chapter provide important information that may be used when selecting the type of display.

Design Goal (L2, L3): Integrate haptic displays with vehicle controls, seats, motion, or other elements of the vehicle.

Supporting Design Guidance

The literature suggests that these haptic displays may be used in support of the design goal.

Types, implementations, and potential benefits and drawbacks of different haptic display types.

Haptic Display Type	Implementation	Potential Benefits	Potential Drawbacks
Vehicle Brake Pulse	One or more short applications of the brakes to create pulses of deceleration.	Effective, highly detectible, may result in lower peak deceleration.	Disruptive; likely to be rated as annoying.
Vibrotactile Seat	Vibration provided through the seat or portion of the seat.	Large display contact area; driver likely to be in contact with display; provides general alert or temporal cue.	Difficult to provide directional alerts; complex alerts require training/experience.
Seat Belt Vibration	Vibration provided through the fabric of a seat belt.	Moderate display contact area; Most drivers are likely to be in contact with display; provides general alert or temporal cue.	Not every driver wears their seat belt; difficult to provide directional alerts; complex alerts require training/experience.
Seat Belt Pre-tensioner	Tightening or tugging of the seat belt.	Helps orient driver to forward roadway.	Not every driver wears their seat belt; may be confused with other events; alert may be viewed as disruptive or annoying.

Note: Vehicle brake pulses and vibrotactile seat displays are most likely to be detected by the majority of drivers. This is due to the potential for large variability in driver seat positions during automated driving and overall seat belt use trends in the United States.

Tip for making trade-off decisions between display effectiveness and user acceptance.

Use this heuristic: Intrusive and annoying haptic displays may lead to better response compliance but may reduce overall user satisfaction.

Note: Vibrotactile haptic displays are often rated to be less annoying and less intrusive compared to auditory displays and kinesthetic haptic displays like brake pulses and steering wheel torque rotation. Brake pulses more frequently result in faster reaction times or better selection of appropriate driving maneuvers.

Discussion

Automotive haptic and tactile displays are an emerging area of research and development, especially in regards to automated driving system driver-vehicle interfaces. The information in this chapter is primarily based on findings from research examining the use of haptic displays in collision warning systems, international standards for displays, and expert judgment. This section provides an overview of haptic display types and some of their key characteristics.

Vehicle *brake pulses* as a haptic display have been tested in both simulator and on-road studies. One study showed that brake pulses can be quite effective at getting a driver's attention and drivers are more likely to detect a brake pulse if it produces a sensation of "jerk" or "self-motion" (Lee, McGehee, Brown, & Nakamoto, 2012; Brown et al., 2005). Overall, brake pulses may lead to lower peak deceleration because the vehicle is physically being slowed by the brake pulses; as a result, drivers may not have to act out hard braking. One usability drawback is that drivers tend to report that vehicle brake pulses are too disruptive, which can lead to annoyance ratings that are unfavorable.

Vibrotactile seats will be discussed in greater detail in other topics within this chapter. The implication from the literature is that vibrotactile seat displays may function best as a general alert or temporal cue. Many design issues limit the use of haptic displays for delivering complex messages; the topic on spatialized vibrotactile seat displays in this chapter addresses this issue.

The use of *seatbelt vibrations* as a haptic display may only serve drivers as a temporal cue or general alert. The correspondence between the warning and where the hazard is located is too tenuous for assuming that locations such as "forward" are automatically implied.

Seat belt pre-tensioning can prompt the driver to the forward roadway for forward crash warning (FCW) systems (Forkenbrock et al., 2011). However, the extent that these messages may be confused with other messages or events must be considered before application in L2 or L3 automated driving settings. Additionally, providing information through the seat belt must be done with the understanding that seat belt use is only 87 percent in the United States (Pickrell & Liu, 2014); thus some users will not benefit from this type of display.

Auditory and visual displays can specify the meaning of a message through direct or indirect means. In-vehicle haptic displays can only deliver messages indirectly, which leaves drivers to interpret the intended meaning. Some haptic display characteristics can enhance how well drivers interpret the meaning of a haptic signal. There is some general agreement across the literature that there should be adequate time for drivers to respond if the warning messages are to be at all more useful than contextual cues from the environment (Lee, McGehee, Brown & Marshall, 2006; Abe & Richardson, 2006). Adequate timing may help considerably when drivers need to derive a message from an indirect signal. When haptic signals are in temporal correspondence with a lane departure, general vibrations from the seat (ISO 17387, 2008) can be quite effective.

Design Issues

Although earlier guidelines generically indicate that tactile warnings may be used to indicate the direction of the hazard and that this directional cue should be reserved for use during imminent situations (Lerner, Kotwal, Lyons, & Gardner-Bonneau, 1996), there is no indication that there is an automatic cognitive process that supports this claim. Studies on tactile warnings provide participants with a large amount of training (Fitch, Hankey, Kleiner, & Dingus, 2011; Jones, Gray, Spense, & Tan, 2008), and experience (Ho, Tan, & Spence, 2005).

Cross References

Selection of Sensory Modality, 4-6; Multimodal Messages, 4-8

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Improving Distinctiveness of Haptic Displays

Introduction

This topic contains information on how to make haptic displays perceptively distinct. The design goal below originates from ISO 17387 (2008) that indicates, "…warnings [should be] clearly distinguishable from other signals of the same type within the vehicle." This topic describes how designers could comply with the ISO standard when using haptic displays.

Design Goal (L2, L3): Ensure haptic warnings are clearly distinguishable from other haptic signals in the vehicle.

Supporting Design Guidance

The best available research on this topic suggests that this design goal can be met when:

- Designers select haptic signals of higher intensity than the natural vibrations that also reach the driver through the vehicle component used to deliver the signal (Ryu, Chun, Choi, & Han, 2010). Note, the duration of high intensity signals can affect driver comfort levels.
- Haptic displays are incorporated in those areas of the vehicle where the driver will remain in contact with (e.g., seat pan, seat belt).
- The duration of high intensity signals is within driver comfort levels.
- Multiple simultaneous vibrations across the body are not used (Gallace, Ho, & Spence, 2007).
- Apparent motion within vibrational surfaces is used to enhance distinctiveness; apparent motion can be accomplished by sequentially activating vibrating motors in time-series. Note that for apparent motion, the minimum distance between tactors motors needs to exceed the two-point threshold (see *Accommodating for Vibrotactile Sensitivity Across the Body, 7-6)*.
- Sufficient training or documentation about function is provided for single systems with multiple vibrotactile haptic signals used to represent different messages.

Examples of perceptibly different vibrotactile signals in the driver seat

(Fitch, Hankey, Kleiner, & Dingus, 2011).

Warning Type	Haptic Signal
Forward Crash Warning (FCW)	Two front tactors in the seat-pan simultaneously activated 5 times in a pulse pattern (200 ms on, 50 ms off pattern).
Curve Speed Warning (CSW)	Front tactors simultaneously activate for 1 second.
In-Vehicle Warning (IVW)	Two front tactors in the seat-pan simultaneously activated 8 times in a double pulse pattern (200 ms on, 50 ms off, 300 ms on, 200 ms off).
Lane Change Warning (LCW)	Left or right tactor in the backrest activation in a pulse pattern.
Lane Departure Warning (LDW)	Left or right tactor in the backrest activate for 1 second.

Note that there is a high degree of training required for drivers to be able to identify multiple unique vibratory messages.

Discussion

This topic uses examples from the existing literature to illustrate how haptic displays could be designed to comply with ISO standard 17387 (2008). The design methods mentioned in this topic are not mentioned within the standard.

Drivers may be engaged in a variety of non-driving related tasks while operating in either L2 or L3 automated driving states (Llaneras, Salinger, & Green, 2013). This may lead to differences in gross body position, in addition to the driver ceasing to have contact with the vehicle controls (i.e., steering wheel and pedal assembly). Areas such as the seat pan (see topic *7-6*) and seat belt should retain reliable levels of driver physical contact during automated operation.

Research on FCW systems has indicated that seat belt pre-tensioning can prompt the driver to the forward roadway (Forkenbrock et al., 2011). However, the potential for this message to be confused with other messages or events must be considered before application in L2 or L3 automated driving settings. Additionally, providing information through the seat belt must be done with the understanding that seat belt use in the United States is only 87 percent (Pickrell & Liu, 2014); thus some users will not obtain information from this type of display.

To ensure that vibrational signals from haptic displays are perceptively different from naturally occurring vibrations, vibrational measurements of the vehicle component that will be used for the haptic display need to be obtained under natural conditions, and then used to determine the vibrational parameters. In designing vibrotactile displays, it is important to note that human sensitivity to vibration is highest at frequencies of 200-250 Hz; frequencies above or below that range require larger amplitude vibrations (Kandel, Schwartz, & Jessell, 2000).

Specific instructions to the driver that indicate there are multiple haptic display information sources within any display or vehicle may lead to better identification and usage of the signal (Ryu, Chun, Choi, & Han, 2010), but without this instruction drivers may still benefit from general alerting properties (Fitch, Hankey, Kleiner, & Dingus, 2011).

Apparent motion can be used to cause contrast between the vibrational signals from a haptic display and any natural vibrations. Natural vibrations do not cause apparent motion for in-vehicle components. Creating apparent motion by progressively activating tactors within a vibrotactile seat display aids driver responses by enhancing detection (Lee, McGehee, Brown, & Marshall, 2006).

Design Issues

Vehicle vibrations provide information about vehicle behavior, road conditions, etc. Additional haptic information should be presented in a manner that is not masked by normal vehicle vibrations.

During L2 or L3 automated driving system operation, drivers may not be optimally positioned to view visual displays and may not detect some auditory signals. Haptic displays can provide a method of alerting the driver in these situations.

Avoid sending simultaneous haptic signals to the driver since humans are poor at processing multiple simultaneous tactile signals (Gallace, Ho, & Spence, 2007). For example, when simultaneous tactile signals are delivered to the hands and gluteus, a driver may only be able to pay attention to one of those signals. There are some cases when multiple vibrating surfaces may be helpful for creating temporal redundancy.

Cross References

Designing Messages for Driver Comprehension, 4-2; Accommodating for Vibrotactile Sensitivity Across the Body, 7-6

Topic References

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Accommodating for Vibrotactile Sensitivity Across the Body

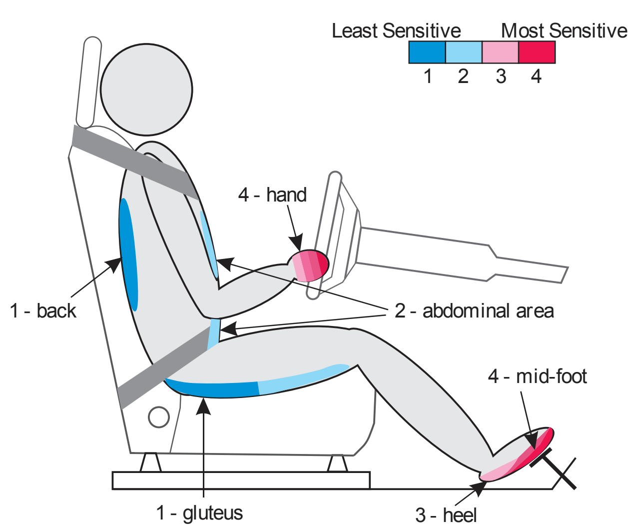
Introduction

This topic describes how a vibrotactile display corresponds to the body's sensitivity to vibration. A driver's ability to perceive a haptic display is a function of vibration amplitude, frequency, duration, surface size, and the body location where the vibrating surface of the vibrotactile display contacts the driver. Designers need to keep this in mind when using vibration to deliver information to drivers.

Design Goal (L2, L3): Select a vibration intensity consistent with the sensitivity of the targeted body location.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when: A larger vibrating surface area is used; this increases perceived intensity for low sensitivity body regions. Optimal vibration frequencies are selected; tactile sensitivity is optimal between 200 and 250 Hz (Kandel, Schwartz, & Jessell, 2000), and highest between 150 and 300 Hz (Jones & Sarter, 2008). Vibration intensity is increased or decreased by adjusting the vibration frequency or amplitude, but not both. Note that only relative settings of amplitude and vibration are possible for some types of vibrotactile displays (e.g., amplitude and frequency are coupled for most tactors that use an eccentric rotating mass). Proper tactor placement is used. For vibrotactile seats, use the ratio of the area of the seat where the message will be presented to the two-point separation threshold between tactor motors to determine the minimum density of vibrating motors within the vibrating surface area (e.g., Reiner, 2003).

Examples of locations for varying vibrotactile intensity.

<table>
<tr><th>Vibration sensitivity across body locations</th><th>Minimum density of vibrating motors</th></tr>
<tr><td>



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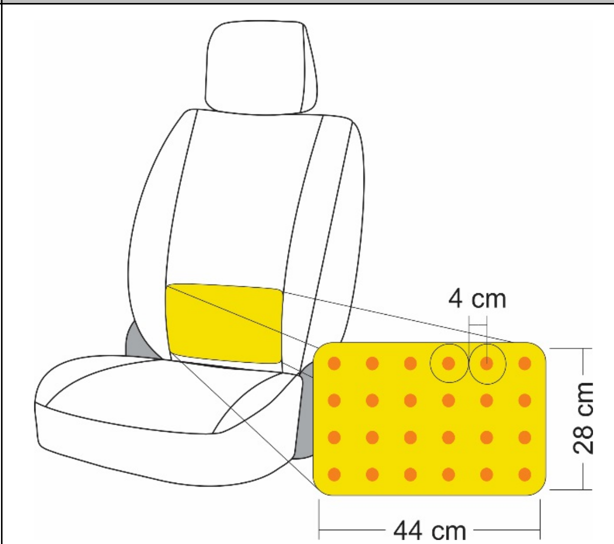

</td></tr>
<tr><td>

This graphic is a generalization of vibration sensitivity. Specifics are left out because of variability due to the following:

- Individual differences in body mass will impact how well vibrations are perceived.
- Clothing (e.g., shoes) will also impede vibrations and affect how well vibrations are perceived.
- Drivers in L2 and higher levels of automation will not necessarily have contact with the wheel or pedals.

</td><td>

The ratio between seat size and two-point threshold for the area of the seat picture above results in a 6x4 matrix of tactor motors using the following:

$$\frac{\mathbf{44\ cm\ (area\ width)}}{\mathbf{2\ x\ 4\ cm\ (two\text{-}point\ threshold)}} = \sim\mathbf{6\ tactors}$$

$$\frac{\mathbf{28\ cm\ (area\ height)}}{\mathbf{2\ x\ 4\ cm\ (two\text{-}point\ threshold)}} = \sim\mathbf{4\ tactors}$$

</td></tr>
</table>

Discussion

The information in this topic was assembled using information from physiological research and a synthesis of research on automotive vibrotactile displays. Basic physiology indicates that mechanoreceptors are distributed differentially throughout the body, and skin density is not the same across the body. Both these factors influence how vibrations are felt. Although there are several examples of in-vehicle vibrotactile displays that contact various body sites (e.g., hands, feet, back, gluteus), empirical research is limited in regards to explaining how to form the correspondence between vibrations from a vibrotactile display with the sensitivity of body sites. There is general agreement from both basic and applied research that indicates detection performance improves when vibration intensity from a vibrotactile display corresponds with physiological sensitivity to vibration.

Basic research has shown that increasing the vibrational surface area of a vibrotactile display increases perceived intensity (Jones & Sarter, 2008; Cholewiak & Craig, 1984). One way this can be accomplished is by activating more tactor motors within a larger array of tactors. There is a linear relationship between the number of tactors used to generate a vibrating surface and a driver's ability to detect the vibrating surface. More active tactors leads to higher perceived intensity. This may be a result of the vibration reaching more of the mechanoreceptors within the skin.

When frequency is kept constant but amplitude gets increased, drivers perceive the frequency of the signal to increase. This perceptual phenomenon is why there are large individual differences across people for their sensitivity to vibration (Jones & Sarter, 2008). Amplitude and frequency of vibration can be used differentially within certain vibrotactile displays (e.g., Rosario et al., 2010) but not all (e.g., Ji, Lee, & Hwang, 2011). When testing vibration parameters, it will be important to note the vibrational elements that accomplish end-user performance goals.

Reiner (2003) calculated the tactor density for a vibrotactile display using the ratio of the size of the driver seat to a *two-point discrimination threshold* distance for the driver's back (e.g., 4 cm). It is advisable that designers measure the two-point threshold using the seat that will contain the vibrotactile display. This is advised because the two-point threshold will depend on characteristics that dampen and diffuse the vibration (e.g., seat fabric, cushioning).

Design Issues

There are some additional considerations when selecting the body site that will receive the information. Large body areas like the gluteus, back and abdominal regions are not often used by people to pick-up information from their environment (Gallace, Tan, & Spence, 2007**.** Although the research is limited on how this effects vibrotactile display types, other haptic displays that deliver messages to the driver through the vehicle control elements (e.g., steering wheel; Suzuki & Jansson, 2003) tend to enhance response time as a result of better correspondence between the warning and the required maneuver.

In addition, the correlated effect of frequency and amplitude in perceiving vibration is different across the body. Displacement has a stronger influence at some locations (e.g., the abdomen) and frequency has a stronger influence at other locations (e.g., the fingertips) (Jones & Sarter, 2008). This will become a design consideration when determining whether or not to increase intensity by changing vibration frequency or amplitude, but relevant research on this consideration is very limited. To support display redundancy, use large vibrating surfaces to ensure the haptic display makes contact with the driver; e.g., this can be accomplished using multiple vibrating motors embedded in the seat (Fitch, Hankey, Kleiner, & Dingus, 2011).

Cross References

Selection of Sensory Modality, 4-6

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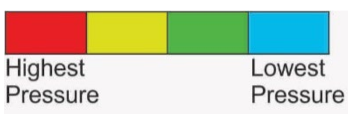
Generating a Detectable Signal in a Vibrotactile Seat

Introduction

This topic contains information on where to place vibrating motors to create a vibrotactile haptic display within the driver seat. Vibrotactile seat displays appear across the literature for a wide variety of applications. A critical design element is to ensure the vibration signal is detectible across drivers and the situations they encounter.

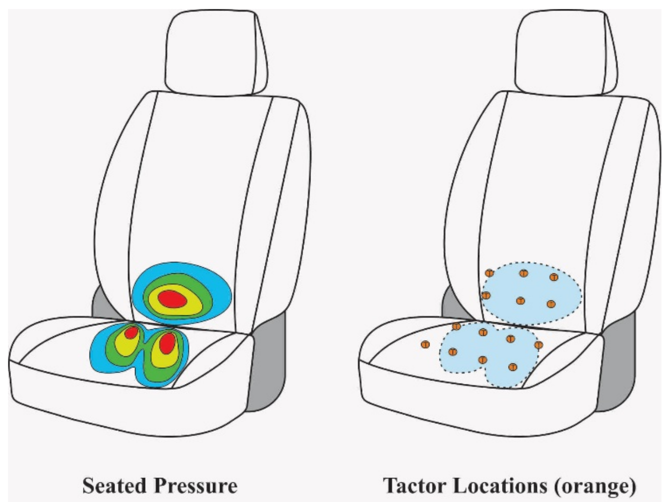
Design Goal (L2, L3): Ensure drivers can feel the vibrations from the vibrotactile seat.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when: There is contact between the driver and the tactile display. To do this, place tactors where seated pressures are the highest. Use measurements of pressure for an average driver in the seated position for the seat that will contain the vibrotactile display. Seat pan pressure distribution plots may be sufficient. Vibrations are measured at the surface of the seat where the intended message is to occur. This will help to ensure that the selected intensity surpasses any attenuation accounted by seat materials. The selected combination of frequency and amplitude has high detectability. A diverse sample of people is used to test different vibration settings.

Illustration of seat pressure distribution for selecting vibrating surfaces.



The *left image* depicts a hypothetical seat pressure distribution and the *right image* depicts where tactor motors could be placed to ensure contact with a driver in this seat.

Note on the illustration: the pressure distribution shown in the left image is an artistic rendition. It does not reflect real data. The tactors in the right image are not to scale.



Examples of the vibration frequency and amplitude for vibrotactile display types at two seat regions.

Detectable vibration measurements from seat pan and and back rest surfaces of a *vibrotactile seat display* [1]:

Seat Region	Frequency Range	Amplitude Range
Seat Pan	26 to 30 Hz	2.02 to 2.65 g
Back Rest	30 to 34 Hz	2.65 to 3.38 g

Discussion

The practice of using seat pressure distributions to place vibratory signals at locations of greater seat pressure is common (Ji, Lee, & Hwang, 2011; Fitch, Kiefer, Hankey, & Kleiner, 2007; Hogema, Sjoerd, Van Erp, & Kiefer, 2009; Reiner, 2010). Three potential reasons for designers and researchers to do this are:

1) Seat-pressure distribution provides an indication of where on the seat the driver is likely to be seated (Reiner, 2010),
2) The transfer of vibrational energy from the vibrating surface to the receptors in the skin that sense vibration is more efficient when friction is highest between the vibrating surface and the driver (Dobbins & McKinley, 2008), and
3) The weight of the driver on the vibrating motor will change the vibration frequency it supplies; this has implications for the amount of frequency and amplitude that should be used to overcome variability in driver size and weight and retain a detectable signal. The response of tactors to this loading effect is not uniform across all tactor types.

Although there are only a few studies where the researchers used an accelerometer to measure vibration at the surface of the seat (Ji, Lee, & Hwang, 2011; Hogema, Sjoerd, Van Erp, & Kiefer, 2009; Higuchi & Raksincharoensak, 2010), this is a far better practice than relying on the operating frequency reported by manufacturers of vibrating tactor motors. Vibrational energy from an embedded tactor has to travel through seat materials to reach the driver. The attenuation of this energy will correspond with the amount of and type of material that the vibration has to travel through to reach the driver. Any adjacent material that absorbs the vibrational energy will cause a similar problem. Thus, any seat material that is positioned between and around the vibrating motor should be of an appropriate impedance to ensure adequate propagation of the vibrational energy (Dobbins & McKinley, 2008).

Although only a few relevant studies demonstrate that both vibration frequency and amplitude are important for making an effective vibrotactile display (Rosario et al., 2010; Ji, Lee, & Hwang, 2011), this concept is well supported and universally accepted.

There are many individual differences that impact how well people detect vibrations. Some known factors are body composition and attire. These elements need to be considered when selecting test participants during the design test phases. Skin mass and clothing impede as well as diffuse vibrational energy.

Design Issues

Vibration Frequency and Amplitude are not always Separately Controllable: Many actuators that are used for vibrotactile seat displays (e.g., a tactor with a spinning eccentric mass controlled by a motor) have only a voltage input. With these types of vibrating motors, frequency and amplitude can only be measured rather than controlled independently (Ji, Lee, & Hwang, 2011). Due to their differing actuation methods, different tactor types have different operating properties. In addition to the peak frequency of the vibrotactile display, the rise time, duty cycle, and amplitude range should be considered. Also, properties such as the response of the display to loading (e.g., a person sitting atop the display) and its surrounding material should be carefully considered as some types of vibrotactile displays rely upon rotation of an eccentric mass to operate and do not respond as well under loaded conditions as other vibrotactile display types.

Postural changes while driving may affect the detectability of a vibrotactile display: One researcher suggests the continual variability in posture can be accounted for by using built-in pressure sensors that detect postural changes. A system can then subsequently adjust the vibrational surface area to correspond to changes in seated pressure. This ensures the tactors located at the highest seated pressure zone are active and the signal is appropriately intense (Reiner, 2010). However, particularly in L3 automated driving systems, the driver's position and posture are less certain than in other vehicles where the driver is in a typical driving posture. This change in loading upon the seat pan may affect the efficacy of a vibrotactile display.

The physical distance between the driver and the vibrating motor plays a role in how much of the signal actually reaches the driver (Dobbins & McKinley, 2008). The greater the distance, the less of the actual signal reaches the driver.

Cross References

Accommodating for Vibrotactile Sensitivity Across the Body, 7-6

Topic References

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Chapter 8. Driver Inputs

This chapter provides information related to driver inputs to automated driving system control functions. Automated driving is an emerging topic and, as such, limited information is available on specific driver input methods. Therefore, the topics included in this chapter were created from basic human factors information, previously published guidelines, and current interface standards.

At a high level, automation controls that must be used while in manual driving (such as those used to activate automation) can be designed with consideration to reducing the frequency and complexity of driver interactions when the vehicle is moving. This will minimize driver distraction and eyes-off-road time during the manual-to-automated driving transition. Optimal systems can support drivers' quickly and easily finding the control, discerning how it is used, and performing the operation with minimal error. Also, the optimal system response following the driver input is timely and intuitive.

It is difficult to definitively guide the design of controls for automated driving system DVI due to the multitude of ways that the systems could be implemented. The system may be designed for one or more specific use cases (e.g., highway speed automation, traffic jam assist, or automated valet parking), could depend on controls that have multiple uses, and could be designed to interface with a nomadic device. Each of these system implementations has its own specific constraints that it imposes on the interface controls.

The following topics are included in this chapter.

- General Guidance for Driver-DVI Interactions
- Control Placement
- Voice Recognition Inputs

General Guidance for Driver-DVI Interactions

Introduction

This topic provides specific information about the design of L2 and L3 automation controls to benefit driver safety and usability. Ideally, the purpose and operation of well-designed controls will be obvious to drivers ((Lerner, Kotwal, Lyons, & Gardner-Bonneau, 1996). Controls that are easy to understand and operate minimize distraction from the driving task during manual to automated driving transitions. Poorly designed controls may adversely affect or impair the operation of primary driving controls. Therefore, designers' carefully consider of the placement and operation of controls in relation to other controls and displays is important (Pomerleau et al, 1999; Stevens et al., 2005). Since this is a broad topic and little published or publically available research specifically addressing L2 and L3 automation control design is available, this guideline is primarily supported by basic human factors information.

Design Goal (L2, L3): Provide controls allowing for operation with minimal mental effort, eye glances, and hand/finger movement.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when controls: Provide **feedback** is timely and clear visual, tactile, or auditory feedback for control activation (AAM 2006; Bhise, 2011). Have **identifiable** labels (symbols or text) that are visible and located close to the control (Bhise, 2011). Are easily understood and **interpretable** (Bhise, 2011). **Placement** does not adversely affect or interfere with other critical system components or primary driving controls. **Size** provides a sufficient grasp area and space for hand/finger clearance (Bhise, 2011). Interaction **pacing** does not require an uninterruptible series of visual-manual interactions (AAM 2006). **Usage** does not compromise the driver's choice to keep at least one hand on the steering wheel at all times. AAM principles state that controls on the steering wheel should not require simultaneous inputs from both hands unless one of the hands only requires a single finger input (AAM 2006).

Methods of control evaluation (Bhise, 2011).

1. Reference and apply available methods, tools, models, customer feedback databases, design guidelines, principles, and standards.
2. Develop and apply ergonomic checklists.
3. Conduct a task analysis of activities involving the control operation, to break down tasks into subtasks, and to look for areas of improvement or situations where driver errors may occur.
4. Conduct in-vehicle evaluations where drivers perform a set of tasks using the control. Data collected can include: time to use the control, errors made, driver likes and dislikes, etc.
5. Include other competitor's products in the above evaluations to provide benchmarking information.

Discussion

Feedback: The feedback or confirmation provided by the system following driver input should be timely and clearly perceptible (AAM 2006). Feedback could include a response to control activation, such as the physical and auditory click of a button press, or a response from a system display, such as an informational dialog box or a system status indicator icon. Timely and perceptible responses allow the driver to quickly determine that the system is reacting as expected and that the change in the system is in reaction to their input. This allows drivers to understand when they have successfully activated automated driving without making second (and perhaps conflicting) inputs or having uncertainty about the system status.

Identification: Controls are often labeled with the control function, its settings, or both. SAE Recommended Practice J1138 (SAE, 2009) provides information on when control functions or settings should be labeled.

Interpretation: Automation controls should be intuitive to operate. The control design and movement should match the driver's expectations of how the system and application function, especially if mapped with similar functions such as ACC or lane keeping.

Placement: Automation controls should be placed such that the operation of the control does not adversely affect the operation of a primary driving control, especially during the transition into or out of automated driving. More information can be found in *Control Placement*, 8-4.

Size: The controls themselves need to be physically usable by the driver. This includes designing space for the driver to grasp the control and space around the control to allow the driver to operate it. As L2 and L3 systems can support mobility across multiple user groups, additional testing with different populations may be required to ensure controls are adequately sized.

Pacing: AAM (2006) provides a range of guidance regarding the pacing of control interactions; these "principles" are generally applicable to the design of the automation DVI. Drivers should be able to control the pace of their interaction with the system and the timing of the system prompts should be predictable for the task operation. Drivers should have the option to not respond, delay a response, or temporarily suspend system prompts altogether. The prompts should not convey that a response is needed urgently and that only one response is possible. If drivers are interrupted, they should be able to resume at the point of interruption or another logical point. If the system times out after a reasonable length of time, it should default in a predictable and appropriate way.

Usage: Overall, manual adjustment of controls should not interfere with a driver's ability to drive safely. In many driving situations, the vehicle can be driven safely with only one hand on the steering wheel, provided the other hand is immediately available for steering if it becomes necessary. Interactions should be designed to require that only one hand at a time needs to be removed from the steering wheel (Stevens et al., 2005).

Design Issues

Complex interactions, such as initial control settings, should be reserved for times when the vehicle is stopped. One way to prevent certain interactions when the vehicle is moving is to use variable-function keys (i.e., keys that are mapped to more than one function based on context) on a keypad or touch-screen. Since these keys are programmable, complex control functions can be made available only at appropriate times. The designer must use good judgment to determine which interactions should be allowed or denied while the vehicle is in motion (Pomerleau et al., 1999; Campbell, Carney, & Kantowitz, 1998). The system should clearly indicate those functions that are not for use while driving and when they are inaccessible (AAM 2006).

Cross References

Control Placement, 8-4; Voice Recognition Inputs, 8-6

Topic References

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Control Placement

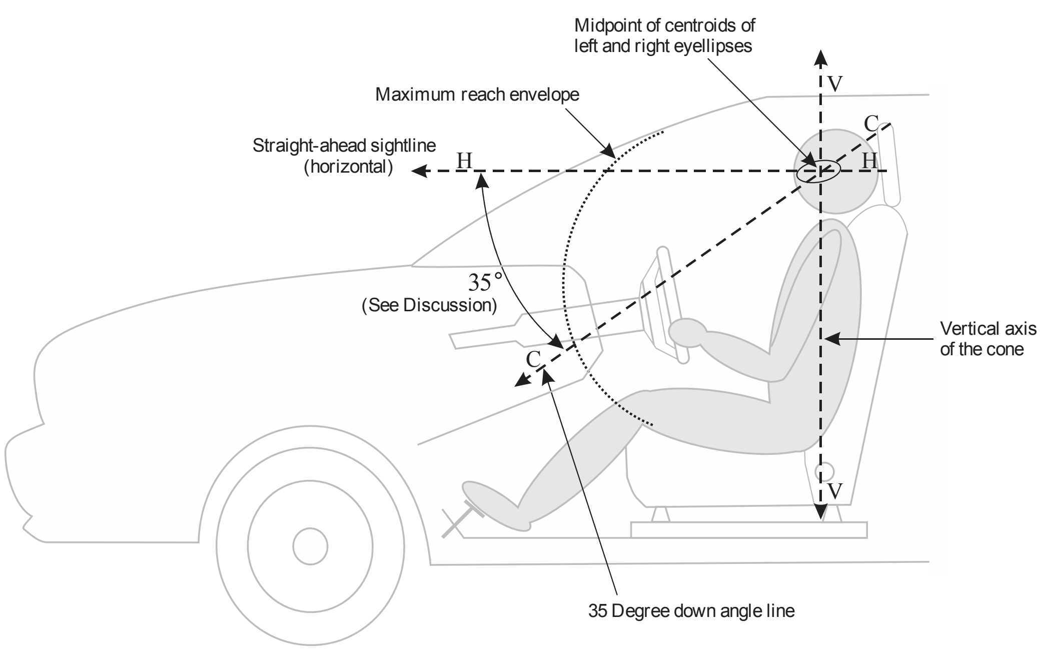
Introduction

This topic provides information about the placement of automation-specific controls in the vehicle. The application and placement of these controls must not interfere with the primary task of driving the vehicle. Drivers are best-supported when they can find, reach, and comfortably use controls in the location that they are placed. There is a lack of published research on the placement of automation controls; therefore, this topic primarily reflects more general in-vehicle control placement information and design convention.

Design Goal (L2, L3): Ensure control placement and operation does not interfere with the driving task or the use of other driving controls.
Supporting Design Guidance
The best available research on this topic suggests that this design goal can be met when controls: • Are easy for drivers to reach and find (Bhise, 2011). • Are located in a visible area or able to be found blindly (Bhise, 2011). • Do not obstruct the driver's field-of-view, vehicle displays, or other vehicle controls (AAM, 2006). • Are placed such that they are not obstructed by other vehicle controls or displays (Bhise, 2011). • Do not require the driver to reach their whole hand through the steering wheel (AAM, 2006).

The following figure shows the ideal zone for locating controls within the vehicle.

Diagram of ideal control placement region relative to the driver (Bhise, 2011).



Adapted from Bhise (2011). Copyright 2011 From Ergonomics in the automotive design process by V. D. Bhise. Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa plc.

Discussion

Little published research on the placement of L2 and L3 automated driving system specific controls is available. However, guidance from standards-setting organizations (AAM, 2006; SAE, 2007; ISO, 2005) and current industry practices with regard to L1 automated systems (specifically, ACC) can provide helpful information for the placement of automation controls.

Controls should be easy for the driver to reach and operate. As shown in the figure on the previous page, controls should be located within the driver's maximum reach envelope. A reach envelope is a depiction of the area that drivers can reach within the vehicle, usually represented by a sector of a circle drawn in front of the seated driver. The values for the maximum reach envelope are described in SAE Recommended Practice J287 (SAE, 2007). The reach distance data in that standard reflects a distance at which drivers can grasp a knob, rather than simply touch a control.

Controls should ideally be located above the 35-degree down-angle cone, which is constructed by a line 35 degrees below the horizontal straight-ahead sightline, through the midpoint of the two eyellipse centroids, and rotated around the vertical axis through that midpoint. A 30- to 35-degree cone is the limit of the area where drivers can look down for a control and still detect stop lamps of lead vehicles (Bhise, 2011). Stevens et al. (2005) and ISO (2005) agree that controls that require lengthy interactions should be placed within 30 degrees of the driver's normal field of view. Controls outside of that area should be able to be found blindly. In addition, frequently used controls should be placed within easy reach and in alignment with the forward view in order to reduce glance times.

Automation controls should not obstruct or interfere with the use of other controls or displays. Stevens et al. (2005) provides good and bad examples of control design. A good design would incorporate controls that are located within fingertip reach of the steering wheel. In contrast, a poorly designed control might include a rotary control concentrically mounted on the steering wheel that requires enough activation force to inadvertently induce a change in steering angle when activated. There is an area of the instrument cluster that can be viewed through the steering wheel; however, if controls are placed in this area, drivers must be able to operate them without reaching their hand through the steering wheel.

The implementation of ACC controls provides useful lessons. Common configurations for ACC controls in production vehicles, including controls for changing headway settings, are found on the outer edge of the steering wheel. This location allows for drivers to more easily manipulate the controls. Placing frequently used low-priority controls (e.g., radio station seek controls) directly adjacent to safety-related controls, such as a gap sensitivity control, is not recommended. The reason for this is that in the course of using the low-priority control, drivers could inadvertently and unknowingly change the settings of the automation control, which could result in the vehicle operating differently than how the driver expects.

Design Issues

Nomadic device (i.e., smartphone) vehicle integration and pass-through voice recognition is becoming more common in new vehicles. When coupled with an L2 or L3 automated driving system, nomadic devices have the potential to directly interact with automation functions, such as providing a means of inputting a navigation destination. These devices provide unique challenges for the DVI designer as the devices change much more rapidly than vehicle software or platforms, and due to the fact that drivers may interact with the devices in a manner different than how they expect to interact with the vehicle. This is a rapidly developing area and further research is needed prior to issuing any stronger guidance for the DVI.

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Voice Recognition Inputs

Introduction

This topic addresses speech interactions between drivers and in-vehicle systems. It focuses on one-way speech input, from the driver to the in-vehicle system. Although speech interactions may place cognitive demands on the driver, unlike visual-manual interactions, they do not require drivers to take their eyes off the road and their hands off the steering wheel. Some research has indicated that voice recognition systems are associated with increased off-road glances (Owens, McLaughlin, & Sudweeks, 2011). Additionally, several simulator and on-road studies of speech interfaces reported better lane-keeping, fewer glances away from the roadway, shorter glance durations, and lower subjective workload when compared with visual-manual interfaces. However, some research has indicated that voice recognition systems are associated with increased off-road glances (Lo & Green, 2013) and, therefore, it cannot be assumed that using a speech input device does not have any consequences for driver performance. Performing secondary tasks using speech input still utilizes cognitive resources and, therefore, does not eliminate risk (Lumsden, 2008). The precise effects of specific system parameters and implementations of speech input on driver workload and driver performance are largely unknown.

Design Goal (L2, L3): Implement speech controlled in-vehicle systems that have minimal input constraints, provide user feedback, and have an error handling strategy.

Supporting Design Guidance

The best available research on this topic suggests that this design goal can be met when the user-input features accommodate the following user requirements:

Conversation Style:

- A natural conversation flow and cadence between user and system is accommodated.
- Input vocabulary is minimized and is consistent with a terse interaction style.

System Feedback:

- When starting an interaction, there is a notification that the system is ready for input.
- After the user provides input, there is feedback so the user knows their input was received.

Error Handling:

- Speech input is only used when the consequences of recognition errors are low.
- The accuracy of the speech recognizer can affect driving performance (see table below).

General Design Goals (Lumsden, 2008) to consider:

- Reduce the user's cognitive load during transitions between automated and manual driving.
- Reduce interaction time.
- Increase task completion rate.
- Use feedback to the user that reinforces correct use.
- Design so that the users can form a mental model of the system behavior.
- Design so that the system is both effective for an experienced user and appealing for a new user.

The accuracy of the speech recognizer, when considered with the number of steps required to complete a task, has a large effect on the success rate of task completion. Shown in the table below is the probability of completing an interaction using only as many steps as are required, given a fixed accuracy level for each step.

		Number of steps required to complete an interaction				
		1	**2**	**3**	**4**	**5**
Accuracy level of each step	**0.99**	0.99	0.98	0.97	0.96	0.95
	0.95	0.95	0.90	0.86	0.81	0.77
	0.90	0.90	0.81	0.73	0.66	0.59
	0.80	0.80	0.64	0.51	0.41	0.33
	0.70	0.70	0.49	0.34	0.24	0.17
	0.60	0.60	0.36	0.22	0.13	0.08
	0.50	0.50	0.25	0.13	0.06	0.03

Discussion

The available literature related to in-vehicle speech input is limited in empirical strength. Most of the design guidance listed above were derived from studies with modest sample sizes, individual interface usability studies, the judgment of experts in the field, or unpublished research results. Additional research in this area is needed to investigate the long-term effects of real-world systems with varying accuracy/error rates, to fully determine the behavioral implications of new speech technologies.

Conversation style: Driver interactions with the system should be paced by the driver (Lumsden, 2008). This leaves the driver free to prioritize safe operation of the vehicle over responses to the in-vehicle system. When speaking, users should be able to converse with the system using a normal conversational cadence. Drivers should not be required to exaggerate their speech or insert artificial delays between words (Department of Defense, 2012). MIL-STD-1472G (Department of Defense, 2012) states that "input vocabulary shall be minimized, consistent with system needs, and selected to provide phonetically distinct elements to eliminate misinterpretation." Additionally, in a study of user preferences and responses to scenarios requiring speech input, 93 percent of commands issued were terse (Aldridge & Lansdown, 1999).

System feedback: Lumsden (2008) recommends that the interaction is initiated with a push-to-talk (PTT; press and release) button followed by a listening tone. This teaches the user to wait for the tone to begin speaking, which is beneficial for the recognition accuracy of the speech recognizer. Manual system input has clear proprioceptive, visual, and manual feedback; however, the feedback provided after giving speech input is less apparent. The system should provide feedback to the user so they know that their input has been received and understood (Department of Defense, 2012). Popp and Färber (1993) investigated methods of providing feedback for non-transparent driver control actions (i.e., actions that have long delays before reactions or barely noticeable reactions) performed using speech input. When providing feedback to nontransparent driver speech input in a simulator, they found that an independent signal tone without visual feedback produced the least negative effects. The visual display without signal tone also performed well. These actions both relate to adjustments in L2 and L3 automated driving systems when a system adjustment may not be immediately apparent.

Error handling: MIL-STD-1472G (Department of Defense, 2012) provides that speech recognition systems may be used when "the consequences of recognition errors are low" and "identifying and correcting errors would be easy." In a simulator study, rejection errors (where the system did not respond to input) caused a smaller proportion of overall task errors (5%) and were more robust against changes in system accuracy levels than substitution errors (where the system matches the user input to an incorrect vocabulary word) (Gellatly & Dingus, 1998) Additionally, systems should require little user training (Department of Defense, 2012).

General design goals: Lumsden (2008) provides a list of general design goals for automotive speech interfaces. It should be noted that although the guidance is consistent with that found in other sources, the list is made from the experience of the authors and their unpublished research. Drivers may still have off-road glances while providing voice input. An examination of a production-type (modified) automotive voice recognition system for text messaging found that voice interactions increased non-driving related glances and increased driver mental workload (Owens, McLaughlin, & Sudweeks, 2011).

Design Issues

A simulator study of an in-vehicle speech system (Kun, Paek, & Medenica, 2007), found that the recognition accuracy of the system affected lane position, when the accuracy level was very low (44%). Push-to-talk (PTT) button use also affected driving performance when the recognition rate was low. When testing recognition rates of 90 percent, 75 percent, and 60 percent in a simulator, Gellatly and Dingus (1998) found that recognition rate did not affect driving performance except for the lowest rate (60%). When looking at studies of recognition accuracy, it appears that the systems function well even with relatively low accuracy levels; however, some negative effects on driving performance have been reported. These issues are primarily relevant during transitions between different automation states, however they should be considered during the design of the DVI.

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Chapter 9. Glossary

Adaptive Automation
: A system operating under an adaptive function allocation system which reallocates functions based on the combination of the operating environment and operator loads and performance.

Adaptive Function Allocation
: An automation strategy building on the complementary approach, which assumes criteria to determine whether functions have to be reallocated, how and when based on changes in the operating environment, loads or demands to operators and performance of operators (Inagaki, 2003). An automation system that operates under an adaptive function allocation is called adaptive automation.

Adaptive Cruise Control (ACC)
: A speed control system that automatically adjusts vehicle speed to maintain a set headway to vehicles ahead without the driver having to use the accelerator or brake. When the sole automation in function (a lane centering system is not engaged), this is a form of Level 1 automation.

Apparent Motion
: A sensation of motion that is associated with the serial activation of static vibrating surfaces. The serial activation of adjacent vibrations causes a sensation that the vibrating surface is moving when, in fact, it is not.

Arcminute
: One-sixtieth (1/60) of one degree (1°).

Auditory Icon
: An auditory signal that sounds like a real object or event, such as a car horn.

Automation
: A device or system that accomplishes all or part of a function that was previously, or could be, performed, in part or fully, by a human operator (Parasuraman, Sheridan, & Wickens, 2000).

Automation Etiquette
: "The set of prescribed and proscribed behaviors that permits meaning and intent to be ascribed to the actions [of the automation]" (Parasuraman & Miller, 2004).

A-weighted Sound Pressure Level (SPL)
: A measure of the intensity of sound using decibels (dB) referenced to sound pressure level (SPL). The measurement is weighted across the frequency spectrum using a profile that accounts for the relative loudness perceived by human hearing.

Calibrated Trust

A state where the automation user's trust in the automation, as well as their use of the automation, is appropriately adjusted to the actual performance of the automation (McGuirl & Sarter, 2006).

Clumsy Automation

A design or situation in which an easy task is automated while a more difficult task is left for human performance, without assistance (Wiener, 1989).

Compensatory Principle

An automation strategy in which assigning system tasks is based on inherent capability so that automated tasks are those that machines are better at than humans while manual tasks are those that humans perform better machines (Fitts List; Fitts, 1951).

Complex Flash

In a visual display, the presentation of multiple signal flashes with varying "on" and "off" times.

Complexity Creep

Refers to the practice of adding features and capabilities over time to systems, potentially reducing the interpretability of information, reducing the predictability of the system, and and/or slowing response time.

Comprehension

The perceptual and cognitive processes by which drivers interpret the meaning of a DVI message. See also Message Comprehension.

Driver Distraction

A diversion or competing activity which takes the driver's attention away from activities which are critical for safe driving.

Driver-Vehicle Interface (DVI)

The means by which a driver gains information about the state of the vehicle (through auditory, haptic/tactile, and visual displays) and provides control inputs to the vehicle.

Driver Workload

A psychological concept that represents the proportion or amount of mental and physical capacity required by the driver to complete a task. Workload encompasses both driving task and situational factors.

Driving Task

A sequence of actions taken by a driver leading to a goal; the driver will normally persist in these actions until the goal is reached (AAM, 2006).

Duty Cycle

In a visual display, the percent of time within a cycle that the alert signal is in the "on" state.

Dynamic Function Allocation

An non-static automation strategy which is complementary, enabling the human and automation to trade-off which functions each performs based on the current situation.

Etiquette

A training approach using a set of heuristics that may enhance and improve a driver's interaction with the system, possibly leading to higher levels of both acceptance and performance.

False Alarm

An alarm that indicates a threat is present when, in fact, no threat exists

Flash Rate (Frequency)

In a visual display, the number of signal flashes per second.

Fundamental Frequency

The lowest frequency in a periodic signal.

Glare

A visual phenomena which occurs when the visual adaptation level is substantially less than the intensity of a light source within the visual field, causing physical discomfort or pain (discomfort glare) and/or reduced visibility (disability glare).

Harmonic Content

The harmonics contained in a complex waveform. Complex waveforms consist of a fundamental frequency and one or more frequencies greater than the fundamental. Harmonics are frequencies that are integer multiples of the fundamental frequency.

Harmonic Series

The sequence of pitches derived from the multiples of its fundamental, or lowest, frequency.

Head-Up Display (HUD)

A visual display that presents data in the area of the windshield in the driver's direct forward view. An image, such as a collision warning icon, is projected onto a transparent surface—usually an angled, flat piece of glass or even the windshield itself—which reflects the image toward the driver. Optically, the image is usually collimated to produce an image that is perceived to be at infinity. This configuration allows the driver to see and focus on the display without looking away from their normal viewpoint.

High Head-Down Display (HHDD)

A type of visual display that is mounted below the driver's normal line of sight (i.e., below the horizon line) but within near peripheral vision. These displays are typically mounted on the dashboard.

Human Factors

An applied, scientific field of study to understand the relationship between devices and systems and their users, with the capabilities and limitations of human beings as the central focus.

Kinesthetic Interface

An interface that provides information to the driver by causing limb or body motion such as when the accelerator pedal "pushes back" against the driver's foot.

Lane Centering Systems (LCS)

A driver assistive system that identifies the lane center and provides a steering torque to maintain the vehicle path along the lane center. When the sole automation in function (ACC is not engaged), this is a form of Level 1 automation.

Lane Keeping Systems (LKS)

A driver assistive system that detects lane markings and provides a steering torque to prevent the vehicle from crossing a lane marking.

Lateral Warning Systems

Collision warning systems, such as blind spot warnings (BSW) or lane change merge warnings (LCM), that provide information about hazards in the adjacent lanes or hazards approaching from the side. These warning systems are primarily dependent on lateral motion and acceleration to determine when to present warnings.

Legibility

Legibility goes beyond visibility or detection; it implies being able to discern shape or character identity based on appearance.

Level of Automation

A taxonomy providing for definitions of different functional levels of automation. NHTSA has defined 5 levels of automation, ranging from no automation (Level 0) to driver-optional automation (Level 4). As the level of automation increases, a greater number of driving subtasks are automated. Level 2 automation provides hands-off/feet-off automation but requires the driver to monitor performance. Level 3 automation provides hands-off/feet-off automation and does not require the driver to monitor performance.

Longitudinal Warning Systems

Collision warning systems, such as forward collision warnings (FCW), that provide information about hazards directly ahead or behind the vehicle. These warning systems are primarily dependent on longitudinal motion and acceleration to determine when to present warnings.

Low Head-Down Display (LHDD)

A type of visual display that is mounted further below the driver's normal line of sight (i.e., below the horizon line) than is found in a HHDD. These displays are typically mounted in places such as the instrument panel or the center console, which places the displayed content farther in drivers' peripheral vision than a HHDD or HUD.

Luminance

The luminous intensity per unit area of light measured as candela per square meter (cd/m^2).

Masked Threshold (MT)

The quietest level of a signal that can be perceived in the presence of noise.

Mental Model

An individual's thought processes and representation about how the automated system works in the real world.

Message Complexity

Refers to the quantity and variety of basic information elements contained within a message, as well as the relationships between these elements, how the driver will use the information, and the value of the information.

Message Comprehension

Refers to the perceptual and cognitive processes by which drivers interpret the meaning of a message presented through a DVI and includes three stages: extractions, recognition, and interpretation.

Message Priority

The order of presentation of two or more in-vehicle messages with the order indicating level of importance.

Mode Awareness

The state of the user correctly understanding under what automation state the system is operating.

Mode Error

An error resulting from a failure of mode awareness. When a user forgets what state of automation the system is in and performs an action appropriate to a different state.

Motion Cue

Visual display alert which contains an element of motion within the "on" state, including bouncing, zooming, and graphical movement.

Multimodal Message

A message consisting of more than one type of signal from the visual, haptic, and auditory modalities.

Nuisance Alarm

An alarm that correctly indicates a threat is present but the driver does not believe the alarm is warranted or needed.

Occlusion

Obstructing the view of an interface, driving scene, or other area of interest.

Out-of-the-loop Phenomenon

A situation where the driver is removed from the normal control process due to automation and experiences a subsequent reduction in his or her awareness of the vehicle's current state and level of performance (Kaber & Endsley, 1997).

Overtone

Complex waveforms consist of a fundamental frequency and one or more frequencies greater than the fundamental. Overtones are any frequencies that are greater than the fundamental. Harmonics, which are frequencies that are integer multiples of the fundamental, are a special type of overtone.

Psychophysical Relationship

The relationship between a stimulus and the perceptions and sensations induced by the stimulus.

Reach Envelope

The area within the vehicle that drivers can reach, usually represented by a sector of a circle drawn in front of the seated driver. The values for the maximum reach envelope are described in SAE Standard J287 and reflect the distance at which drivers can grasp a knob, rather than simply touch a control.

Redundancy

More than one cue for a specific threat or hazard which can be given at the same time using two or more modes or repeated across time with either the same or different modes.

Residual Function Principle

The earliest automation philosophy in which the automation is designed to perform as many functions as possible while the remaining functions are performed by the human.

Resolved Musical Structure

A sequence based on natural scales, which consist of musical notes ordered by pitch (e.g., tones with frequencies that correspond to notes that can be played on a piano).

Seat Pressure Distribution

The pressure from a seated person acting as a force on a seat (e.g., how the pressures from body weight are distributed across a seat-pan and back-rest).

Secondary Task

A voluntary task which distracts a driver's attention away from the main driving task at hand.

Semantic Content

The meaning contained in an auditory message, whether presented as a speech message or other type of auditory signal.

Semitone

The smallest musical interval that is commonly used in Western music. Mathematically, the frequency of a semitone is $2^{1/12}$ times the frequency of the fundamental when the semitone is a higher pitch than the fundamental.

Short-cycle Automation

Automated task operation in which manual control is alternated with short periods of automation based on other operation environment elements, either the automation or the human can instigate the change in control.

Situational Awareness

"The perception of the elements in the environment within a span of time and space, the comprehension of their meaning and the projection of their status in the near future." (Endsley 1995)

Spatially Localized Cues

Auditory cues that are perceived to emanate from a specific location within a three dimensional sound stage.

Take Control Message

Communication from the automation system to the driver requesting that the driver resume manual control of the vehicle.

Transfer of Control

The transition between states of manual and automated control of the vehicle.

Tell-tale

An indicator which displays the status of a situation or system.

Transport Information and Control Systems (TICS)

Systems which improve the safety and efficiency of land-based transportation through the use of automation and technology.

Two-point Threshold

The minimum separation distance needed for two distinct objects to be felt separately, rather than as a single sensation, based off of *two-point discrimination*, which is an ability to distinguish adjacent objects that are touching the skin as being independent objects.

Veiling Luminance

Uniform luminance that causes a reduction in contrast as it washes over the retina. It is caused when the eye is exposed to a light source that is substantially more intense than the adaptation level.

Vibrotactile Interface

An interface which provides information to the driver using physical vibrations of the seat, seat belt, foot pedals, or steering wheel against the driver's body.

Chapter 10. Index

Chapter 11. Abbreviations

AAM .... Alliance of Automobile Manufacturers
ACAS ....Automotive Collision Avoidance System
ACC ....adaptive cruise control
ADAS ....Advanced Driver Assistance System
AHS..Automated Highway System
ANSI..American National Standards Institute
BSMS .... blind spot monitoring system
BSW..blind spot warning
CCW ....cautionary collision warning
cm ....centimeter
CSW...Curve Speed Warning
DARPA.. Defense Advanced Research Projects Administration
dB...decibel
dBA .... decibel (A-weighted)
DVI ....Driver-Vehicle-Interface
EID ....Ecological Interface Design
FAA ....Federal Aviation Administration
FCW ....Forward Collision/Crash Warning
FHWA ....Federal Highway Administration
FMCSA ....Federal Motor Carrier Safety Administration
FMVSS...Federal Motor Vehicle Safety Standards
FTA ....Federal Transit Administration
g .... acceleration/deceleration level (1 g = approx. 9.8 m/s^2)
HDD ....head-down display
HHDD...high head-down display
HMI ....human-machine interface
HUD ....head-up display
HVAC ....heating, ventilating, air conditioning
Hz..Hertz

ICW .... imminent collision warning

IP .... instrument panel

ISO .... International Organization for Standardization

ITS .... Intelligent Transportation Systems/Society

IVW .... in-vehicle warning

L0 .... Level 0 Automation

L1 .... Level 1 Automation

L2 .... Level 2 Automation

L3 .... Level 3 Automation

L4 .... Level 4 Automation

L5 .... Level 5 Automation

LCDAS .... Lane Change Decision Assist System

LCS .... Lane Centering System

LCW .... lane change warning

LDW .... lane departure warning

LED .... light-emitting diode

LHDD .... low head-down display

ms .... millisecond

MT .... masked threshold

nm .... nanometer

NHTSA .... National Highway Traffic Safety Administration

OEM .... original equipment manufacturer

OOTL .... out-of-the-loop

PTT .... push-to-talk

RITA .... Research and Innovative Technology Administration

s .... second

SAE .... Society of Automotive Engineers

SPL .... sound pressure level

TICS .... Transport Information and Control Systems

TTC .... time-to-collision

V2V .... vehicle-to-vehicle

VPT .... variable priority training

Chapter 12. Equations

Glare Angle and Display Luminance 5-4

$$L_{veil} = I_{glare} \cdot \left(\frac{10}{\theta^3} + \left[\frac{5}{\theta^2}\right] \cdot \left[1 + \left(\frac{A}{62.5}\right)^4\right]\right)$$

Where:

L_{veil} = Veiling luminance
I_{glare} = Luminous intensity of glare source
θ = Glare angle
A = Driver age

Viewing Distance and Symbol Height 5-10

$$V = 60 \cdot \text{Arctan}\left(\frac{H}{1000 \cdot D}\right)$$

Viewing Distance and Visual Angle

$$H = 1000 \cdot D \cdot \text{Tan}\left(\frac{V}{60}\right)$$

Visual Angle and Symbol Height

$$D = \frac{H}{1000 \cdot \text{Tan}\left(\frac{V}{60}\right)}$$

Where:

H = Symbol height in millimeters
D = Viewing distance in meters (0.5-1.1m)
V = Visual angle subtended in arcminutes

7-6

Minimum Density of Vibrating Motors

$$\frac{A_w}{2 \times T}$$

$$\frac{A_h}{2 \times T}$$

Where:

A_w = Area width
A_h = Area height
T = Two-point threshold

Chapter 13. Relevant Documents from the United States Department of Transportation, SAE International, and International Organization for Standardization

The table below provides an alphanumeric list of standards, best practices, and general resource documents which may or may not be directly cited in chapter topics but, if not, present additional information relevant to the design issues discussed in this document.

Document	Description
ANSI/HFES 100-2007 Human factors engineering of computer workstations Year: 2007 Document Type: U.S. National Standard	Specifications for acceptable applications of human factors engineering principles and practices related to computer workstation design and configuration, defined as an operator-machine system comprised of associated user-interface components (input devices, output devices, and furniture).
ANSI Z535.3 American national standard. Criteria for safety symbols Year: 2011 Document Type: U.S. National Standard	General criteria for the design, evaluation, and use of safety symbols for identifying and warning against specific hazards.
CIE 146 CIE equations for disability glare Year: 2002 Document Type: International Standard	Definitions for disability glare equations for veiling luminance.
DOT 37-13 Visual-manual NHTSA driver distraction guidelines for in-vehicle electronic devices Year: 2013 Document Type: Federal Guidelines	Provides nonbinding, voluntary guidelines to discourage excessively distracting devices in vehicles. Applicable to original equipment in-vehicle electronic devices used for secondary tasks such as communications, entertainment, information gathering, or navigation through visual-manual means.
ISO 2575 Road vehicles--Symbols for controls, indicators and tell-tales Year: 2010 Document Type: International Standard	Specifications for symbols for use on controls, indicators and tell-tales. Applicable to passenger cars, light and heavy commercial vehicles, and buses. Also included are colors of possible optical tell-tales for informing drivers of either correct operation or malfunctioning of related devices.
ISO 3864-3 Graphical symbols--Safety colours and safety signs--Part 3: Design principles for graphical symbols for use in safety signs Year: 2012 Document Type: International Standard	Principles, criteria and guidance for designing graphical symbols for use in safety signs (described in ISO 3864-1), and for the safety sign element of product safety labels (described in ISO 3864-2).

Document	Description
ISO 4040 Road vehicles--Location of hand controls, indicators and tell-tales in motor vehicles --- Year: 2009 Document Type: International Standard	Specifications for the location of controls in motor vehicles, and for certain combinations of functions for multifunction controls. Applicable to hand-operated controls, indicators and tell-tales in all motor vehicles, excluding motorcycles and mopeds, as defined in ISO 3833.
ISO 7731 Ergonomics--Danger signals for public and work areas--Auditory danger signals --- Year: 2003 Document Type: International Standard	Specification of criteria for the recognition of auditory danger signals, especially in situations of high ambient noise.
ISO 9921 Ergonomics--Assessment of speech communication --- Year: 2003 Document Type: International Standard	Specification of requirements for the performance of speech communication for verbal alert and danger signals, information messages, and speech communication. Methods for predicting/assessing subjective and objective performance in practical applications are described. Examples are provided.
ISO 11429 Ergonomics--System of auditory and visual danger and information signals --- Year: 1996 Document Type: International Standard	Specification of warning and information signals which differentiate between degrees of urgency, from extreme urgency to All Clear situations.
ISO 15005 Road vehicles--Ergonomic aspects of transport information and control systems--Dialogue management principles and compliance procedures --- Year 2002 Document Type: International Standard	Description of ergonomic principles for designing dialogues between drivers and the vehicle's transport information and control systems (TICS) while the vehicle is in motion, including specification of compliance verification conditions related to the principles.
ISO 15006 Road vehicles--Ergonomic aspects of transport information and control systems--Specifications for in-vehicle auditory presentation --- Year: 2011 Document Type: International Standard	Ergonomic specifications for auditory information displays related to transport information and control systems (TICS), primarily when the vehicle is in motion although it may also be applied when the vehicle is stationary. Requirements and recommendations for in-vehicle auditory signals from TICS, as well as characteristics and functional factors for maximizing auditory signal intelligibility and utility while helping prevent auditory or mental overload are provided.
ISO 15007-1 Road vehicles--Measurement of driver visual behaviour with respect to transport information and control systems--Part 1: Definitions and parameters --- Year: 2014 Document Type: International Standard	Definitions of key terms and parameters used in the analysis of driver visual behavior for both real-world trials and laboratory-based driving simulator studies.

Document	Description
ISO 15008 Road vehicles--Ergonomic aspects of transport information and control systems--Specifications and test procedures for in-vehicle visual presentation Year: 2009 Document Type: International Standard	Specification of minimum requirements for image quality and legibility of visual displays containing changeable information presented while the vehicle is in motion, including test methods and measurements for assessing compliance where necessary. Applicable to mainly perceptual components of the visual information such as character legibility and colour recognition; not applicable to factors affecting performance and comfort such as coding, format and dialogue characteristics, pictorial information or images, maps and topographic representations.
ISO 15623 Transport information and control systems--Forward vehicle collision warning systems--Performance requirements and test procedures Year: 2002 Document Type: International Standard	Specification of performance requirements and test procedures for systems which warn the driver of short inter-vehicle distance and closing speed which could cause a rear-end collision with other vehicles. Applicable to operations on roads with curve radii over 125m or higher radius curves.
ISO 16673 Road vehicles--Ergonomic aspects of transport information and control systems--Occlusion method to assess visual demand due to the use of in-vehicle systems Year: 2007 Document Type: International Standard	Procedure for measuring visual demand during the use of visual or visual-manual interfaces while the vehicle is in motion. Applicable to both original equipment and aftermarket in-vehicle systems.
ISO 17287 Road vehicles--Ergonomic aspects of transport information and control systems--Procedure for assessing suitability for use while driving Year: 2003 Document Type: International Standard	Procedure for assessing whether transport information and control systems (TICS), or a combination of TICS with other in-vehicle systems, are suitable for drivers while the vehicle is in motion. Topics include user-oriented TICS description and context of use, TICS task description and analysis, the assessment process, and documentation. (Does not recommend specific variables for assessing suitability nor defines criteria for establishing the suitability of use of a TICS table while driving.)
ISO 17361 Intelligent transport systems--Lane departure warning systems--Performance requirements and test procedures Year: 2007 Document Type: International Standard	Specifications for the definition of the system, classification, functions, human-machine interface (HMI) and test methods for in-vehicle lane departure warning systems which are appropriate for highways and highway-like roads; warnings at roadway sections having temporary or irregular lane markings (such as roadwork zones) is not within the scope. Applicable for systems which provide warnings only (no automatic mitigation action) for passenger cars, commercial vehicles and buses.

Document	Description
ISO 17386 Transport information and control systems-Maneuvering aids for low speed operation (MALSO) Performance requirements and test procedures --- Year: 2010 Document Type: International Standard	Specification of minimum functionality requirements for light-duty vehicles, e.g., passenger cars, pickup trucks, light vans and sport utility vehicles (motorcycles excluded) equipped with MALSO systems such as detection of and information on the presence of relevant obstacles within a defined (short) detection range. It defines minimum requirements for failure indication as well as performance test procedures; it includes rules for the general information strategy but does not restrict the kind of information or display system. (Sensing technology is not addressed; visibility-enhancement systems without distance ranging and warning are not addressed. For reversing aids and obstacle-detection devices on heavy commercial vehicles, see ISO/TR 12155.)
ISO 17387 Intelligent transport systems--Lane change decision aid systems (LCDAS)--Performance requirements and test procedures --- Year: 2008 Document Type: International Standard	Specification of system requirements and test methods for Lane Change Decision Aid Systems (LCDAS) and their use on forward moving cars, vans and straight trucks in highway situations (does not address LCDAS for use on motorcycles or articulated vehicles).
ISO 26022 Road vehicles--Ergonomic aspects of transport information and control systems--Simulated lane change test to assess in-vehicle secondary task demand --- Year: 2010 Document Type: International Standard	An estimate of secondary task demand derived through a laboratory base-method, which quantitatively measures human performance degradation on a primary driving-like task while a secondary task is being performed. The method, for both original equipment and aftermarket in-vehicle systems, applies to in-vehicle information, communication, entertainment, control, manual, visual, haptic and auditory single and combination systems for passenger cars, but cannot be used to test secondary tasks requiring that speed variations be performed.
ISO 26262 Road vehicles--Functional safety --- Year: 2011 Document Type: International Standard	Intended to be applied to electrical and/or electronic systems in production passenger vehicles (excludes heavy vehicles). The standard covers functional safety across the product lifecycle, provides an automotive-specific risk-based approach for determining risk arising from malfunctioning electrical/electronic systems, and provides requirements for validating and confirming measures to ensure sufficient and acceptable level of safety.
ISO/TR 12204 Road vehicles--Ergonomic aspects of transport information and control systems--Introduction to integrating safety critical and time critical warning signals --- Year: 2012 Document Type: Technical Report	General, informational guidance for integration of safety critical and time critical warning signals into existing in-vehicle messages presented to a driver; does not provide guidance in integration of non-critical signals, nor how to design an integrated warning HMI.
ISO/TR 16352 Road vehicles--Ergonomic aspects of in-vehicle presentation for transport information and control systems--Warning systems --- Year: 2005 Document Type: Technical Report	Literature survey of human-machine interface of warning systems in vehicles which discusses efficiency, acceptance of different modalities and combinations of warnings, and design parameters of visual, auditory and tactile warnings.

Document	Description
ISO/TS 14198 Road vehicles--Ergonomic aspects of transport information and control systems--Calibration tasks for methods which assess driver demand due to the use of in-vehicle systems Year: 2012 Document Type: Technical Specification	Procedures for developing secondary, calibration tasks used in a dual-task setting for assessing drivers' attentional demand when using in-vehicle systems. Advice provided for selecting an appropriate candidate calibration task and includes its application, experimental design, data collection, and procedures for analysis.
ISO/TS 15007-2 Road vehicles--Measurement of driver visual behaviour with respect to transport information and control systems--Part 2: Equipment and procedures Year: 2001 Document Type: Technical Specification	Guidelines for analyzing driver visual behaviour to assist in planning evaluation trials, specifying/installing data capture equipment, as well as analyzing, interpreting and reporting visual-behaviour measurement. Applicable to road trials and simulated driving environments, but is not applicable to the assessment of head-up displays.
ISO/TS 16951 Road vehicles--Ergonomic aspects of transport information and control systems (TICS)--Procedures for determining priority of on-board messages presented to drivers Year: 2004 Document Type: Technical Specification	Provides formal procedures and two alternate methods for determining the priority of in-vehicle messages, including traveler, navigation, traffic advisories, warnings, system status and other information, as well as messages from other sources such as telephones, warnings, and tell-tales.
MIL-STD-1472G Department of defense design criteria standard - Human engineering Year: 2012 Document Type: Military Standard	General human engineering design criteria for military systems, subsystems, equipment, and facilities with the intent of optimal system performance given inherent human capabilities and limitations.
SAE J287 Driver hand control reach Year: 2007 Document Type: Recommended Practice	Description of the boundaries of hand control locations that can be reached by a percentage of different driver populations in passenger cars, multi-purpose passenger vehicles, and light trucks (Class A vehicles); not applicable to heavy trucks (Class B vehicles).
SAE J941 Motor vehicles drivers' eye locations Year: 2010 Document Type: Recommended Practice	Establishment of the location of drivers' eyes inside a vehicle for passenger cars, multi-purpose passenger vehicles, and light trucks (Class A vehicles) and heavy trucks (Class B vehicles) (eyellipses have not been updated from previous versions of SAE J941).
SAE J1138 Design criteria--Driver hand controls location for passenger cars, multipurpose passenger vehicles, and trucks (10,000 GVW and under) Year: 2009 Document Type: Recommended Practice	Description of design criteria related to the location and labeling of hand controls (does not include hand-held devices such as remote controls or cellular phones).

Document	Description
SAE J1757-1 Standard metrology for vehicular displays Year: 2007 Document Type: Standard	Methods to determine optical performance for Flat Panel Displays in all typical automotive ambient light illumination, focusing on High Ambient Contrast Ratio, a critical element for display legibility in a sunshine environment.
SAE J2364 Navigation and route guidance function accessibility while driving Year: 2004 Document Type: Recommended Practice	Establishment of both a static method and an interrupted vision method for determining which navigation and route guidance functions should be accessible to the driver while the vehicle is in motion; applicable to original equipment and aftermarket route-guidance system functions for passenger vehicles. Does not apply to visual monitoring tasks which do not require a manual control input, such as route following, nor to voice-activated controls or passenger operation of controls.
SAE J2365 Calculation of the time to complete in-vehicle navigation and route guidance tasks Year: 2002 Document Type: Recommended Practice	A method for calculating the time needed to complete navigation system-related tasks which may be used as an assessment tool for safety and usability of alternative navigation and route guidance system interfaces. Does not consider voice-activated controls, voice output from the navigation system, communication between the driver and others, or passenger operation. Applicable to both original equipment and aftermarket route-guidance and navigation system functions for passenger vehicles.
SAE J2395 ITS in-vehicle message priority Year: 2002 Document Type: Recommended Practice	Description of a method for prioritizing ITS in-vehicle messages and/or displayed information which is applicable to original equipment and aftermarket ITS message-generating systems for passenger vehicles and heavy trucks. A prioritization value is assigned to specific messages or units of information which is then used to determine the order that simultaneous, or overlapping, in-vehicle messages are presented to the driver.
SAE J2396 Definitions and experimental measures related to the specification of driver visual behavior using video based techniques Year: 2000 Document Type: Recommended Practice	Description of key terms and metrics applied in the analysis of video-based driver eye glance behavior, intended to assist development of a common source of reference for driver visual behavior data. Data collated and analyzed from this document allow comparisons to be performed across different device evaluations and experimental scenarios.
SAE J2399 Adaptive cruise control (ACC) operating characteristics and user interface Year: 2003 Document Type: Standard	Specifications for the minimum requirements for Adaptive Cruise Control system operating characteristics and elements of the user interface; applicable to original equipment and aftermarket ACC systems for passenger vehicles (including motorcycles). Not applicable to commercial vehicles nor variations on ACC, such as "stop-and-go" ACC.
SAE J2400 Human factors in forward collision warning systems: Operating characteristics and user interface requirements Year: 2003 Document Type: Information Report	Description of the elements for a Forward Collision Warning user interface, and requirements and test methods for these systems. Applicable to original equipment and aftermarket FCW systems for passenger vehicles including cars, light trucks, and vans, but does not apply to heavy trucks, nor does it address integration issues associated with adaptive cruise control (ACC).

Document	Description
SAE J2402 Road vehicles—Symbols for controls, indicators, and tell-tales Year: 2010 Document Type: Standard	Specification of symbols for use on controls, indicators, and tell-tales which is applicable to passenger cars, light and heavy commercial vehicles, and buses.
SAE J2678 Navigation and route guidance function accessibility while driving rationale Year: 2004 Document Type: Recommended Practice	Description of the rationale used by the Navigation Function Accessibility Subcommittee for the development and content of the SAE J2364 Recommended Practice: Navigation and Route Guidance Function Accessibility While Driving.
SAE J2802 Blind spot monitoring system (BSMS): Operating characteristics and user interface Year: 2010 Document Type: Recommended Practice	Specification of the minimum recommendations for Blind Spot Monitoring System (BSMS) operational characteristics and elements of the user interface. Applicable to original equipment and aftermarket BSMS systems for passenger vehicles, but not motorcycles or heavy trucks, nor does it address Lane Change Systems (which monitor a larger area behind the vehicle). A visual BSMS indicator is recommended.
SAE J2808 Road/lane departure warning systems: Information for the human interface Year: 2007 Document Type: Information Report	Recommendations for Road Departure Warning Systems (RDWS) operational characteristics and elements of the user interface. Applicable to original equipment and aftermarket systems for light-duty vehicles on relatively straight roads with a radius of curvature of 500m or more, and under good weather conditions.
SAE J2830 Process for comprehension testing of in-vehicle icons Year: 2008 Document Type: Information Report	A process for testing driver comprehension of safety, navigation, infotainment or other ITS message symbols or icons.
SAE J2831 Development of design and engineering recommendations for in-vehicle alphanumeric messages Year: 2012 Document Type: Information Report	Recommendations for alphanumeric messages communicated to the vehicle by external (e.g., RDS, satellite radio) or internal (e.g., infotainment system) sources *while the vehicle is in-motion*. Applicable to OEM (embedded) and aftermarket systems. Does not cover ergonomic issues regarding display characteristics such as viewing angle, brightness, contrast, font design, etc.
SAE J3016 Taxonomy and definitions for terms related to on-road motor vehicle automated driving systems Year: 2014 Document Type: Information Report	Taxonomy and operational definitions for the full range of levels of automation in on-road motor vehicles as a foundation for discussion and further standards development within the "Automated/Autonomous Vehicle" community.

Chapter 14. References

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