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Human Factors Design Guidance For Driver-Vehicle Interfaces

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13. ABSTRACT (Maximum 200 words)

This document provides human factors design guidance for driver-vehicle interfaces (DVIs). The guidance provided is based on the findings of current high-quality research (including both the best-available scientific literature and current research being conducted by agencies of the United States Department of Transportation), as well as basic human factors concepts. The design guidance is provided as a complementary resource to other documents and resources, as well as an augment to industry research and existing guidance from the National Highway Traffic Safety Administration. The information in this document may be useful to researchers, designers, and original equipment manufacturers and Tier-1 suppliers seeking to ensure the compatibility of DVIs with driver limitations and capabilities.

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Table of Contents

Chapter 1. Introduction

Background

Considerable progress has been made toward reducing the incidence of property loss, injuries, and fatalities on the Nation's highways. However, motor vehicle crashes continue to impose a heavy toll upon road users. The National Highway Traffic Safety Administration reports that in 2012 there were approximately 5,615,000 police-reported motor vehicle crashes resulting in approximately 23,000 people killed (with a fatality rate of 1.13 fatalities per 100 million vehicle miles traveled) and approximately 2.1 million injured (NHTSA, 2014).

A number of active safety systems exist or are in development that may address these crashes. Technologies such as forward collision warning (FCW) are being implemented in an increasingly large number of new vehicles. Research from the United States Department of Transportation and industry examining such technologies is helping to develop an information backbone for the surface transportation system that will support applications to enhance safety, mobility, and sustainability. However, these promising applications, no matter the source of information that causes them to activate, present a unique set of challenges for designers of driver-vehicle interfaces (DVIs).

These advanced safety technologies produce a large amount of information. Sometimes, the information may be complex (e.g., warning of a vehicle in a blind spot prior to a lane change, or providing notification of an upcoming hazard). In some cases, this complex information may need to be provided to, comprehended, and rapidly acted upon by the driver to avoid a collision. Thus, ensuring that the DVI enables drivers to quickly and easily access needed information is of great importance with respect to driver performance.

The purpose of this document is to provide Human Factors design guidance, based on the best-available research and established Human Factors concepts, for DVIs. Note that this document is not meant to serve as a standard. Resources such as Federal Motor Vehicle Safety Standards (FMVSS), SAE and ISO standards, and the *Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices* (NHTSA, 2013) exist that provide design guidance for DVIs. Instead, this document it is meant to serve as a complementary resource for original equipment manufacturers (OEMs), Tier-1 suppliers, and the automotive research community in designing DVIs that enable rapid, consistent, and reliable communication between the vehicle and driver.

Design Guidance Development

This human-centric design guidance for the DVIs is intended to provide a more in-depth understanding of driver limitations and capabilities for designers. The developers of this information have focused on providing a clear, relevant, and easy-to-use reference of human factors data for DVI design and operation. The development team has worked cooperatively with other researchers in order to ensure that relevant research and suggestions are integrated into the document. 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, in particular, by designers who lack specific training or knowledge 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, guidelines, human factors concepts, and user characteristics among DVI developers and designers.

Automotive DVI research in general has typically focused on the design of safety system DVIs. Therefore, the available research cited within this document is primarily drawn from safety research. However, the basic design guidance that this document provides may also help inform the design of non-safety related DVIs (i.e., infotainment and driver convenience systems). Additionally, this document provides information from recent and on-going research in the emerging field of vehicle-to-vehicle (V2V) technology. 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 versus 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, etc.) of the original data sources cited, our syntheses of and conclusions regarding these data sources.

While DVI design information can be a valuable tool and resource for designers, it is not without limitations. Many factors must be considered, and tradeoffs examined, prior to finalizing a DVI design. Some of these factors include regulation and industry or international standards. This DVI design guidance is intended to augment—not replace—the judgment and experience of developers as they design DVIs in this environment.

Scope

This document provides goals and guidance for the design and development of DVIs, for both light- and heavy-vehicles, based on current knowledge of driver capabilities and limitations.

Objectives

The *Human Factors Design Guidance for Driver-Vehicle Interfaces* document provides information on topics based on the best-available research and literature. It also includes information on a number of topics based on knowledge gained from recent and on-going NHTSA-sponsored research.

Organization of this Document

Beyond this 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 11). Following the design chapters are a set of reference chapters with supplemental information that may be useful for either a specific topic or for DVI design in general. This supplemental material (Chapters 12 to 18) includes tutorials, 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 used to develop the design guidance and tutorials.

Chapter 2. How to Use This Document

Two-Page Format

In this document a consistent two-page format is used to present the individual human factors topics provided in Chapters 3 to 10. On each page the chapter title is indicated by centered, bold type within the header. As described in more detail below, the left-hand page presents the title of the topic; an introduction and overview of the topic; a high-level design goal; design guidance; a graphic, table, or figure that augments the text information; and the rating associated with the topic. The right-hand page 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.

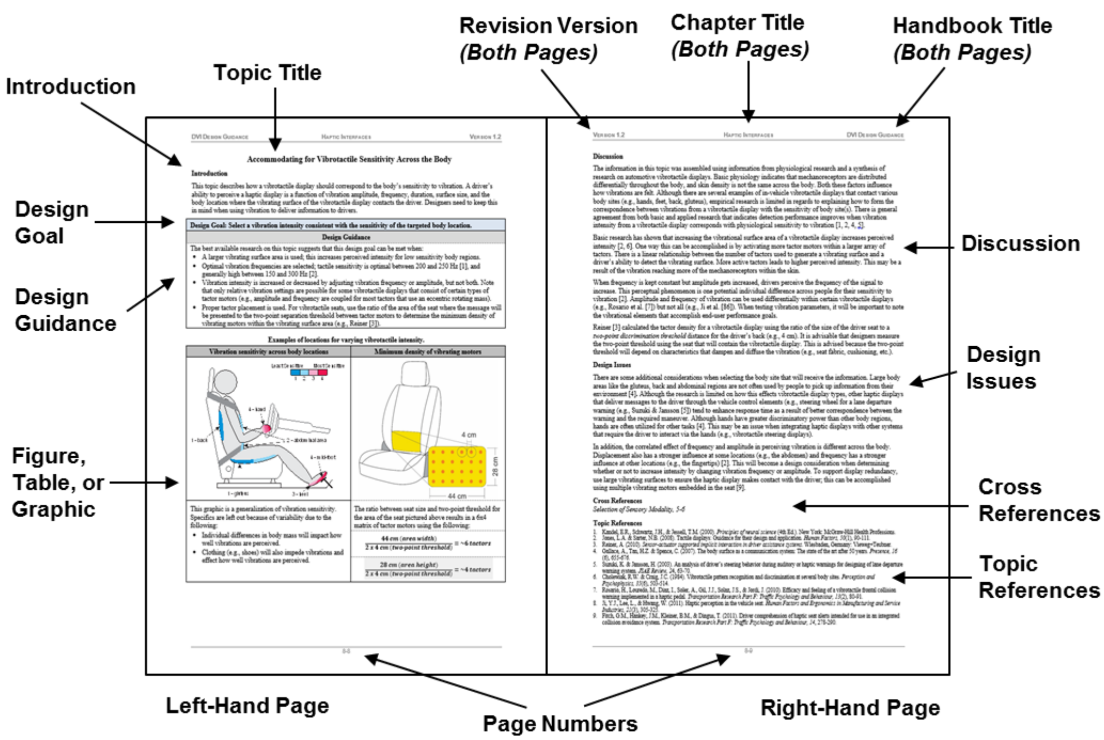

Figure 2-1. Topic format used in this document.

The Left-Hand Page

The topic title is indicated by centered, bold type at the top of the left-hand page.

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 specifies an objective with regard to driver responses or activities that the driver-vehicle interface design may support. 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 a number of 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 the available research. A key goal within this subsection is to present the design guidance 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 guidance 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 design guidance or a particular 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 Right-Hand Page

Discussion

This subsection briefly summarizes the rationale behind the choice of the 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 information to others involved in developing a particular 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 this 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.

Use of Acronyms

All acronyms and abbreviations are listed in alphabetical order in Chapter 15.

Chapter 3. General DVI Considerations

This chapter provides design guidance that address high-level design considerations related to driver needs and abilities. These include topics such as driver customization of system elements, driver distraction, driver workload considerations, and driver training. Unlike most other chapters, Chapter 3 focuses on more general information about these topics, rather than specific design recommendations. The objective is to discuss considerations for system design; the way in which these considerations will apply depends upon the specific system or application.

Topics addressed in this chapter:

- Distraction
- General Workload Considerations
- Workload From Secondary Tasks
- Providing Drivers With Information on System Function and System Messages
- Developing Driver Training Material

Distraction

Introduction

Driver distraction is a diversion away from activities critical for safe driving toward a competing activity [1]. In some scenarios, DVIs may contribute to distraction. This topic provides a list of the principles covered in the NHTSA *Visual-Manual Driver Distraction Guidelines for In-Vehicle Electronic Devices* [2]. The NHTSA guidelines should be considered a critical source of DVI design information relevant to distraction. NHTSA has published driver distraction guidelines that provide requirements for in-vehicle displays and applications. The current topic does not provide specific design guidance, but rather provides a list of where to find recommendations on specific topics in the NHTSA *Visual-Manual Guidelines*. More information on this topic is also available in the Alliance of Automobile Manufacturers AutoAlliance Statement of Principles [3].

Design Goal: Design in-vehicle tasks and messages that do not divert attention from activities critical for safe driving.

Design Guidance

The table below lists topics covered by the NHTSA *Visual-Manual Guidelines* that are related to distraction and in-vehicle systems.

Recommendation/Guideline Topic from AutoAlliance Statement of Principles [3]	Topic Covered	Section in *Visual-Manual Guidelines* [2]
No Obstruction of View	Device location in relation to driver.	V. A
Easy to See and Reach	Driver access to a device.	V. B
Maximum Display Downward Angle	Device location in relation to driver.	V. C
Lateral Position of Visual Displays	Device location in relation to driver.	V. D
Maximum Size of Displayed Textual Information	Size of visually presented text.	V. E
Per Se Lock Outs	Device usage while driving.	V. F
Acceptable Test-Based Lock Out of Tasks	Tasks performed while driving.	V. G
Sound Level	Sound level of a device.	V. H
Single-Handed Operation	Driver control of the vehicle.	V. I
Interruptibility	Driver interaction with the device.	V. J
Device Response Time	Feedback provided to the driver by the device.	V. K
Disablement	Presentation of non-safety-related information to the driver.	V. L
Distinguish Tasks or Functions Not Intended for Use While Driving	Driver access to devices while driving.	V. M
Device Status	Presentation of system status information.	V. N
Visual Task Completion	Driver interaction with the device.	-
Driving Relevant Information	Information presented to the driver.	-
Speech-Based Communication Systems	Driver interaction with the device.	-
Pace of Interaction with Device	Driver interaction with the device.	-

Discussion

Driver distraction can contribute to motor vehicle crashes when a driver's attention is diverted away from the driving task at a time when there is an unexpected hazard or change in the driving situation (e.g., lead vehicle braking, a pedestrian crossing the road, etc.). Distraction may also be associated with lapse of vehicle control, resulting in unintended speed changes or allowing the vehicle to drift outside of the lane boundaries [4]. This diversion of attention away from the driving task can be caused by a secondary task that shares the same resources that are needed for safe driving. The greater the extent to which an action shares the same resources with a driving activity, the higher the degree of incompatibility between that action and driving, and the higher is the expected degree of distraction induced by performance of that action while driving [1]. While a driver's attention should not be diverted away from activities critical for safe driving, there are safety-related instances in which redirecting attention is beneficial. For example, if a driver is checking a blind spot to make a lane change while a leading vehicle suddenly brakes, a forward crash warning will draw the driver's attention away from the lane change task. In this case, the redirection of attention to the more safety-critical event is appropriate.

Secondary tasks are numerous and many may benefit drivers in some way (e.g., inputting a destination into a navigation system, receiving traffic information updates, etc.). Some drivers may become accustomed to performing secondary tasks while driving, leading to secondary tasks becoming the rule rather than the exception [4]. In order to engage in a secondary task without degrading driving performance, there needs to be a balance between the benefits and costs associated with engaging in the secondary tasks. Proper message prioritization may help reduce the disruptiveness of secondary task messages [e.g., 5]. Drivers need to have an awareness of the risks associated with secondary tasks so they are able to make safe choices while driving [1].

Design Issue

The NHTSA *Visual-Manual Guidelines* give a specific list of per se lock outs [2], while the AutoAlliance Statement of Principles [3] identify different categories of tasks that should not be available to the driver while driving. There is some exploratory pilot research on methods to assess situational awareness as a tool for evaluating driver performance under distracting conditions (e.g., visual search on a digital map [6]).

Distraction can occur due to drivers taking their eyes off the forward roadway to perform an in-vehicle task and when drivers return their eyes back to the forward roadway while still in the process of performing the in-vehicle task [7, 8]. This results in cognitive distraction [9, 10]. An example of this is alternating glances between the forward roadway and a GPS device [11].

Cross References

Workload From Secondary Tasks, 3-6

Topic References

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General Workload Considerations

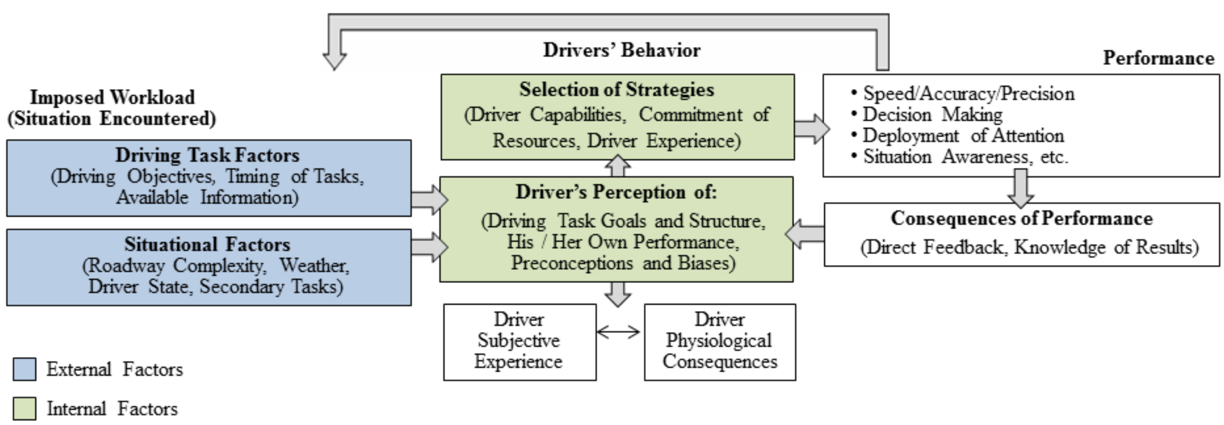
Introduction

This topic provides a high-level discussion that is intended to introduce the concept of driver workload. Workload has been conceptualized in a number of ways: time demand of a task, the number of activities, or complexity of activities. At a high level, workload is a psychological concept that represents the proportion or amount of a driver's mental and physical capacity (i.e., perceptual, cognitive, psychomotor) that is used to complete a task. Primary driving tasks, such as controlling the vehicle, scanning for hazards, navigating, etc. impose workload on the driver. Workload increases or decreases based on the driving conditions (e.g., roadway complexity, weather, traffic flow, etc.) or driver state (fatigued, alert, etc.), but it is always present to some degree.

Design Goal: Design information displays for secondary tasks in a manner that imposes minimal workload.
Design Guidance
The best available research on this topic suggests that this design goal can be met when the following points are considered: • Workload is complex and difficult to predict on a moment-to-moment basis. Use caution when making assumptions about when workload is low. • In-vehicle tasks that use the same information-processing resources (e.g., listening to an audio system and hearing an auditory warning) require drivers to switch between the tasks, which can degrade driving performance. • Driver workload is a limited resource. Secondary tasks performed during normal driving may exceed available total driver workload capacity. This may lead to reductions or deterioration of driving capabilities [1, 2].

Conceptual framework for relating variables that influence driver performance and workload.

(See the Discussion section on the next page for a description of the figure.)



Adapted from Hart and Staveland [3]

Discussion

As shown in the previous figure, there are external factors (driver task, situational) and internal factors (driver capabilities, strategies and perceptions) that lead to a driver's subjective experience of workload. Driving task factors include driving objectives, available information, and timing of tasks (self-paced versus forced-paced). Situational factors include a variety of aspects such as roadway complexity (a winding road versus a long straightaway), weather, driver state and secondary tasks. Task and situational factors influence a drivers' perception of the driving task goals and performance. This perception affects how drivers make decisions or employ strategies about how to deal with the workload they are encountering based on their own capabilities and available resources. Note that some of this driver coping may even occur at an unconscious level, particularly with highly-practiced actions, such as speed or lane maintenance. These types of "automatic" behaviors typically require less attention or deliberation on the drivers' part [4]. The driver's perceptions related to workload also lead to a subjective experience of the workload as well as physiological consequences, such as increased heart rate or pupil dilation. How drivers cope with the workload by deploying resources across tasks affects their driving performance, which feeds back into the driving situation and yields consequences that impact driver perceptions related to workload. Given the wide range of factors that can impose or influence workload, it is difficult to predict the level of driving-related workload (or driver's capacity for secondary tasks) at any one time.

Drivers are able to adapt to conditions to some degree and manage elevated workload (e.g., slowing their speed down, increasing their headway with the car in front of them) [5]. In order to adapt to the high workload driving situation, drivers may begin by skipping those tasks that are not immediately relevant for driving or deliberately *not* engaging in the tasks until they are not driving, or have a safe place to pull over. Drivers can also ask for a passenger's help in performing the tasks, if possible. If workload remains high and the adaptations no longer help with the eroding safety margins, driver errors are more likely to occur.

In addition to drivers proactively managing their workload, Advanced Driver Assistance Systems (ADASs), can also help drivers by reducing workload imposed by basic driving tasks. These benefits, however, are limited to specific situations. Navigation systems, for example, have been shown to reduce driver workload when driving to a destination in an unfamiliar area [6]; however, out-of-date or incorrect information in the navigation system can lead to confusion, which in turn may result in increased workload. Adjusting the navigation system while driving can also lead to an increase in workload as less attention is being devoted to the driving task [5]. Driver assist systems, such as a Congestion Assistant, a system that combines features of a congestion warning system and an automated headway control system, can potentially reduce driver mental workload while driving in the congestion, but can also possibly increase the workload just before the congestion has started [7].

Design Issues

There is some evidence from desktop driving simulator studies indicating that high workload can reduce the effectiveness of highly urgent alerts [8]. Participants in these studies were asked to indicate when they heard a sound that was already presented in a set of sounds (i.e., an *n*-back task). This task is thought to capture and occupy working memory, which in turn can elevate mental workload. The method is effective at increasing workload but is not necessarily associated with typical driving. While the generalizability of this study may be limited due to the method used to elevate workload and the limitations of the driving simulator used, the results suggest that elevated workload may reduce the effectiveness of warnings and alerts.

Cross References

Workload From Secondary Tasks, 3-6; Tutorial 4: Heavy Vehicles Characteristics and Driving Environment Relevant to DVI Design, 12-59

Topic References

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Workload From Secondary Tasks

Introduction

As covered in *General Workload Considerations*, the relationship between driving and workload is complicated. This topic describes how additional workload from common secondary tasks may impact driving performance.

Design Goal: Prevent user interactions with the DVI from interfering with driving.
Design Guidance
The following information reflects the AutoAlliance Statement of Principles [1], and may help minimize workload resulting from secondary driving tasks. • Systems with visual displays should be designed such that the driver can complete the desired task with sequential glances that are brief enough to not adversely affect driving (AutoAlliance 2.1). • The system should not require uninterruptible sequences of manual/visual interactions. The driver should be able to resume an operator-interrupted sequence of manual/visual interactions with the system at the point of interruption or at another logical point in the sequence (AutoAlliance 3.3). • In general (but with specific exceptions), the driver should be able to control the pace of interaction with the system. The system should not require the driver to make time-critical responses when providing input to the system (AutoAlliance 3.4). • System functions not intended to be used by the driver while driving should be made inaccessible for the purpose of driving interaction while the vehicle is in motion (AutoAlliance 4.2a). • The system should clearly distinguish between those aspects of the system that are intended for use by the driver while driving, and those aspects (e.g., specific functions, menus, etc.) that are not intended to be used while driving (AutoAlliance 4.2b).

Summary of empirical findings related to the impacts of secondary tasks on driver performance [2].

Task Category	Eye Glances	Object Event Detection	Vehicle Control	Workload Rating
Drive without Secondary Tasks (Baseline)	Eyes-on-road of 83% and mirror scanning of 14.3% of time. On-road glances averaged 8s long. More than 30 glances to the road, on average.	Higher detection rate across all three detection events.	Good lateral control. Few lane exceedances and low speed variability.	Not measured.
Visual-Manual High *E.g., Manual Dialing, Destination Entry*	More glances to road relative to Baseline, due to drivers making shorter glances and cycling back and forth between the task and road.	Lower detection rate relative to Baseline and Auditory-Vocal tasks.	Reduced lateral vehicle control due to longer task duration. More speed variability and lane exceedances.	Highest workload ratings compared to all other tasks.
Visual-Manual Low *E.g., HVAC Adjustments, CD/Track 7*	Reduced eyes-on-road time compared to Baseline (34-61%) and reduced mirror scanning (7%). Decrease in on-road glance duration compared to Baseline (less than 2s on average).	Lower detection rate relative to Baseline and Auditory-Vocal tasks.	Better lateral vehicle control due to shorter task duration. Less speed variability and fewer lane exceedances.	Lower than Visual-Manual High, but higher than both Auditory-Vocal tasks.
Auditory-Vocal High *E.g., Travel Computation, Route Guidance*	Similar eyes-on-road time as Auditory-Vocal Low tasks, but an increase in task-related glances of looking up or at the rearview mirror.	Lower detection rate relative to Baseline, but better than all other tasks.	Reduced lateral vehicle control relative to both Visual-Manual task types.	Lower than both Visual-Manual tasks, but higher than Auditory-Vocal Low tasks.
Auditory-Vocal Low *E.g.: Sports Broadcast, Book-on-Tape*	Increased eyes-on-road time compared to Baseline (88%) and reduced mirror scanning (11%). Increased in on-road glance duration compared to Baseline (9-16s).	Lower detection rate relative to Baseline and Auditory-Vocal High tasks, but better than all Visual-Manual tasks.	No systematic effect of the auditory-vocal tasks on lanekeeping performance.	Lowest workload ratings relative to all other tasks.

Discussion

The points listed in the design guidance represent the subset of the AutoAlliance Statement of Principles [1] that corresponds to secondary tasks. Principle 2.1 addresses the design of visual displays and glances required to complete the task. Principles 3.1, 3.3, and 3.4 relate to how a driver interacts with the in-vehicle system, while Principles 4.2a and 4.2b relate to the type of information or function that is available or not available to the driver while driving. According to the AutoAlliance [1], a task is defined as a sequence of control operations (i.e., a specific method) leading to a goal at which the driver will normally persist until the goal is reached, e.g., obtaining guidance by entering a street address using the scrolling list method until route guidance is initiated. The AutoAlliance principles state that systems with visual displays should be designed such that the driver can complete the desired task with sequential glances brief enough not to adversely affect driving. When designing a visual or visual-manual task intended to be used while the vehicle is in motion, the principle gives the criteria of having single-glance durations generally not exceeding 2 s or having task completion not require more than 20 s of total glance time to task displays or controls; note that according to the NHTSA *Visual-Manual Guidelines* [3], the total glance time to task displays or controls should not exceed 12 s, showing a difference in opinion between the two documents in regard to this value.

The table information was developed using data from Angell et al. [2], in which driver performance data on a range of secondary tasks commonly performed in vehicles was collected in a laboratory setting, on public highways, and on a test track. The secondary tasks imposed varying levels of demand on the driver's input modalities (auditory or visual), output modalities (manual or vocal), and working memory (verbal or spatial) and represented device and interface types either currently in use or that are expected in future telematics systems. Each of the tasks across the three venues was compared to baseline routine driving without any secondary task.

The table shows the specific ways in which driving related behaviors were affected by different types of secondary tasks. Specifically, visual-manual tasks had a more pronounced effect on driving performance than the auditory-vocal tasks, consistent with the driver's need to remove their eyes from the road ahead and look inside the vehicle to perform this type of task. Within each task type, there were also varying levels of demand between the individual tasks. Visual-manual tasks that were rated with higher workload (e.g., Destination Entry task or Manual Dial task) produced an increase in the number of glances to the road, whereas, visual-manual tasks that were rated with lower workload (e.g., HVAC Adjust task or CD/Track 7 task) produced a reduction in the number of glances to the road (see the second row, second column in the table on the previous page for an explantion). In terms of vehicle control, auditory-vocal tasks that were rated with higher workload (e.g., Travel Computation or Route Instruction) showed a reduction in lateral vehicle control whereas auditory-vocal tasks that were rated with lower workload (e.g., Sports Broadcast or Book-on-Tape Listen), showed better lateral control compared to auditory-vocal tasks with higher workload. According to the results of Angell et al. [2], states of driver workload that produced overload or interference with driving performance negatively affected several aspects of driving behavior, confirming that workload-induced distraction is multidimensional in nature. These results also revealed that different patterns of interference/degradation across the categories of performance were associated with different types of tasks (auditory-vocal versus visual-manual). This suggests that multiple measures should be used when assessing the potential for interference; however, for visual-manual and auditory-vocal tasks, eyeglance measures and event detection measures were key in evaluating the extent of intrusion on driving performance.

There are also other task types that can reduce or interfere with driving performance such as forced-paced tasks, which require an immediate response from the driver. This task type is considerably more likely to interrupt the driver at times when their attentional allocation should be on the control of the vehicle and interaction with the roadway. A study by Xie and Salvendy [4] showed that mental workload was significantly affected by time-related pressure. The workload in a self-paced multitask environment was 29 percent lower than the workload in a forced-paced multitask environment and19 percent lower than the workload in a forced-paced, single-task environment.

Design Issue

The guidance provided in this topic does not apply to crash warnings because these are qualitatively different than the tasks listed above since they require both less time to respond and simpler responses.

Cross References

Distraction, 3-2; General Workload Considerations, 3-4

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Providing Drivers With Information on System Function and System Messages

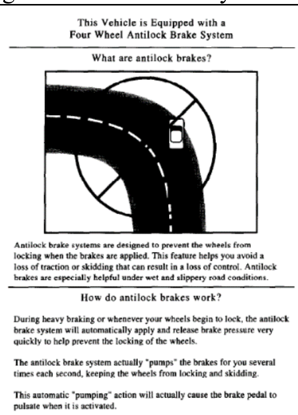
Introduction

Most drivers will not receive specific training on the features of their car (e.g., safety features like antilock brake system (ABS) or a collision avoidance system) [1]. Due to variability in driver age, experience, aptitude, and other factors, it is an imposing challenge to provide information that effectively helps drivers understand how to use the systems in their vehicle. This topic provides guidance for creating informational material about in-vehicle systems and system messages.

Design Goal: Provide drivers with clear and concise information on system function, states, and how to respond when the system activates.
Design Guidance
The best available research on this topic suggests that this design goal can be met when designers: • Provide a description of the interface and describe examples of behavioral options that correspond with what is presented by the interface [2, 3]. • Provide detailed information on system limitations in the owner's manual as per standard and best practices documents (e.g., ISO 17387 [4]). • Maximize effectiveness of informational material by making it short, meaningful and concise in content, and eye catching [3].

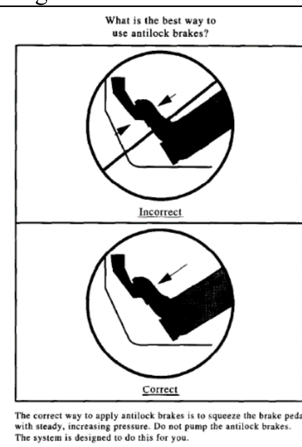
Example of a multipage informational pamphlet on antilock brakes (ABS) (from Mollenhauer et al. [3])

Page 1: Introduces the system and describes its function



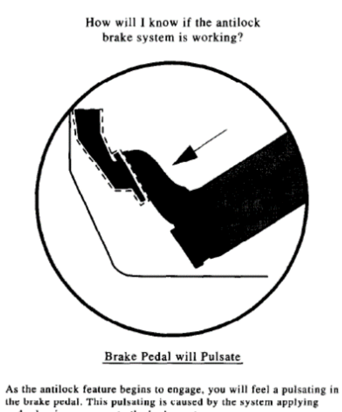
- Describes the purpose of the system, how the system actually works and where the system will be most useful.
- Illustration shows a use case, e.g., ABS leads to better steering during heavy braking, which may reduce off-road crashes on curves.

Page 2: Shows how to use the system



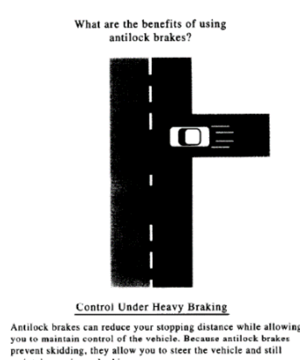
- Indicates correct and incorrect use when active.
- Continues to indicate how the system works.

Page 3: Shows how drivers will know when the system is active



- Shows which cue indicates the system has activated.
- Continues to indicate how the system works.

Page 4: Describes benefits to drivers



- Lists benefits of the system.
- Illustration shows another use case, e.g., ABS leads to shorter braking distance, which may reduce intersection entry crashes.

Figures republished with permission of Pergamon, from Mollenhauer et al. (1997). Anti-lock brake systems: An assessment of training on driver effectiveness. *Accident Analysis and Prevention, 29*; permission conveyed through Copyright Clearance Center, Inc.

Discussion

The literature supports the idea of providing drivers with a detailed description of in-vehicle driver support systems. However, assembling useful information in an effective manner is far from a simple practice. Potential benefits of effective instructional material may include drivers reporting increased familiarity with the system, as well as reduced confusion about what system messages mean. More importantly, with full descriptions of the meaning of interface states, drivers may be more likely to use the system in a beneficial way when mental workload is high [2]. Adequate information provided by proper labeling could also reduce the need for extensive training, and this topic is better referred to in previous design guidance literature [5]. Instructional information regarding what to do when the system is activated may be useful to drivers [3].

According to standards and best practices, there are some system details that should be provided in the owner's manual. As an example, for a lane change decision assist system (LCDAS), the owner's manual should include the following statement, "this system may not provide adequate warning on curves tighter than *x* meters radius" where *x* is replaced by the tightest curve radius for which the system is designed. The LCDAS manual should also indicate that if a trailer is put on the back of the vehicle, the vehicle dimensions become different, which affects the function of the system [4]. It should be noted, however, that while this type of information should be included in the owner's manual, in the form it is presented above, drivers may experience difficulty operationalizing the information.

For certain systems, a short informational pamphlet could be sufficient for providing adequate information to drivers. For example, to illustrate the correct response when an ABS has been activated, a 4-page, informational pamphlet was effective in transferring knowledge of the system [3]. The informational pamphlet conveyed verbal knowledge that included: (1) a definition of ABS, (2) a general explanation of how ABS works, (3) an explanation of how drivers will know ABS is active, and (4) an explanation of the benefits of using ABS correctly. Drivers who read the pamphlet stopped at shorter distances when driving on ice and tended to use the correct braking technique. The information in the pamphlet was formatted to be short and easy to read (e.g., it took less than 5 minutes for drivers to review). Another goal was to make the material visually appealing to increase the likelihood of other drivers reading the material.

Design Issues

Despite the availability of useful and well put-together information, there is a chance that it will not be reviewed at all [6]. There is also a high chance that the information will not be understood by all those who review it. Yet, informational material may be useful for those who do review it regularly when they switch vehicles. The transfer of knowledge gained from experience with one vehicle to a second vehicle should not be assumed. For example, Lerner et al. [7] noted that, after a few days of exposure to a particular auditory only FCW system, a new and different auditory alert was associated with a delay in brake response. Although these findings have limited generalizability due to the laboratory-like conditions and very high participant exposure to the FCW, they do illustrate some limitations to the transfer of experiential knowledge.

Another consideration is that drivers tend to over-generalize the purpose of available systems. They may think that the assistance the system provides also applies to situations beyond the design purpose. For example, drivers who owned cars with collision avoidance systems were presented with scenarios during which the systems in their cars would not be functionally useful, yet many of the drivers were still erroneously confident that their systems would assist them in these scenarios [6]. Driver training material (covered in Topic 3-10) is one method that can be used to help drivers generalize less often to situations in which the functionaility of a system is comprised.

Cross References

Using Coverage Zones to Provide Lane Change Information, 4-8

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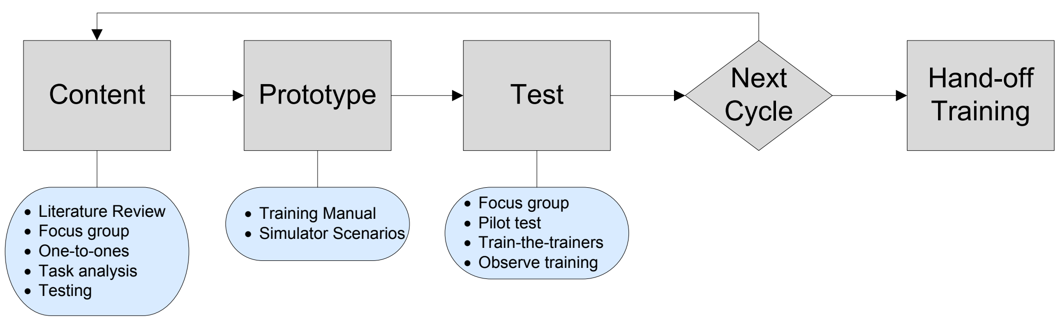
Developing Driver Training Material

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 using rules of thumb that the designers of training curricula have honed over the previous decades by incorporating methods that they "believe should be there," but have been minimally influenced by contemporary findings from the behavioral sciences [1]. This topic summarizes recent findings from the behavioral research literature on several training methods that could be used to train drivers on the use of in-vehicle systems including, but not limited to, safety applications. This DVI design topic may be most applicable to systems that are especially novel, complex, or those within the heavy truck or bus environment, for which driver training programs are more frequently developed and used.

Design Goal: Develop and evaluate training for systems or applications in a manner consistent with the goals of the application.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • Information on system functionality and system limits is provided in a driver training program [2]. • Variable priority training (VPT) is used, especially for complex multi-component systems. In VPT, trainees are presented a complex task divided into subtasks between which they vary their attentional priority [3, 4]. (e.g., divide the task into Parts A and B. Start with the trainee devoting 80 percent of their attention to Part A and 20 percent to Part B. Then, dedicate 20 percent to Part A and 80 percent to Part B. Finally, practice with 50 percent attention to both.). • Error-training is used. It can reduce driver overconfidence and influence trainees to generate their own coping strategies for when they encounter novel situations not covered in training [5]. • Training on the use and function of in-vehicle systems occurs after beginner drivers have obtained the basic and rudimentary skills needed for safe-driving [2].

Simple 5-stage iterative training design model [6].



–**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, focus groups, and task analyses. Literature searching can be useful for preparing for user-testing and obtaining information about driver tasks (e.g., previous task analyses [7]). 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, etc.

–**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**: This is a decision phase where the results of testing 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 training material may not be necessary for all applications or user groups (e.g., it may be more of a priority for safety-relevant applications with the heavy-vehicle environment), a training program should be systematic, deliberate, and informed by research findings from the instructional design literature. A training program on driver safety systems can entail different aspects of the system itself. Training sessions on support systems should focus on the functionality of the system, including information on limitations and any potential for malfunction [2]. 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 of the possibility of certain LDW systems (e.g., with optical sensors) providing warnings based on older lane markings that may not be entirely relevant.

Training programs should include information on how to read and interpret the DVI, available action options (e.g., brake, steer, or both during a hazardous event), and instructions on acting out maneuvers (e.g., steer right or left, brake harder) when the system is activated [8]. Instilling procedural knowledge by making suggestions to drivers on what to do in order to maintain a safe field of travel is an effective strategy to help transform drivers' knowledge about safety imminent situations into the behavioral skills that are useful for crash avoidance [9, 10]. 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 assistive systems during high workload situations. Such behavioral skills could become relatively immune from deterioration in a broad range of contexts [9], especially if variable priority and error training methods are used. Novice drivers, in particular, may also need general reminders on risk and situation awareness, personal attitudes, and risk acceptance in order to drive responsibly and appropriately even when the car is equipped with in-vehicle safety applications [11].

Different training strategies may be employed to ensure that drivers gain knowledge on and retain useful driving strategies. The variable-priority training strategy is an effective training strategy for complex tasks. 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 [4]. Drivers trained with this strategy tend to learn faster and reach higher levels of mastery compared with training programs that emphasize all components equally [3, 4]. 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 more effective than the guided-error training where learners learn vicariously from examples of others' errors [5]. In some cases, different training settings may be necessary. Drivers between 70 and 89 years old benefit more after training is complete when instructors provide feedback on actual driving in addition to classroom training [12]. 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.

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Chapter 4. Design Guidance for Safety Messages

This chapter provides a collection of general human factors information relevant to interface design. This information directly impact driver use of, and benefit from, safety systems. The chapter consists of system implementation topics. For some topics, real-world examples of deployment methods are provided.

Topics included in this chapter:

- False and Nuisance Warnings
- Multimodal Warning Messages
- Warning Stages
- Providing Forward Collision Warnings That Accommodate Driver Brake Reaction Time
- Using Coverage Zones to Provide Lane Change Information

False and Nuisance Warnings

Introduction

False alarms are defined as alarms that indicate a threat when no threat exists. They can cause driver distraction, incorrect decisions and/or responses, and distrust in the crash warning system (CWS). Furthermore, they may increase reaction time to true warnings. Nuisance alarms are defined as alarms that correctly indicate a potential threat, but that the driver does not believe are warranted or neededperhaps because the driver was already aware of the threat or believes that the threat will be resolved without driver intervention. However, drivers may not necessarily make distinctions between false and nuisance alarms. This topic provides information for minimizing the occurrence of false and nuisance alarms, and reducing the negative effects of these warnings on driver performance and acceptance of the CWS.

Design Goal: Minimize false and nuisance warnings and their effects on driver performance and acceptance.
Design Guidance
The best available research on this topic suggests that this design goal can be met when the following false/nuisance alarm rates and strategies for collision avoidance systems, and emerging technologies such as connected vehicle systems, are considered: • Longitudinal warning systems (forward crash warning, curve speed warning, etc.) –Limit imminent crash warning nuisance alarms to 0.5 per 100 miles [1]. –Mitigate driver annoyance with nuisance warnings by avoiding the use of auditory and haptic for cautionary crash warnings. • Lateral warning systems (lane change warning, blind spot warning, etc.) –Drivers are not likely to consider even relatively high rates of nuisance alarms to be annoying, as long as the warnings are unobtrusive and presented via the visual modality only [2, 3]. • General Strategies –From Lerner, Kotwal, Lyons, and Gardner-Bonneau [4] and Horowitz et al. [5], some strategies for minimizing the frequency and impact of false/nuisance warnings include: 1.Deactivate a warning device automatically when it is not needed during a particular driving situation (i.e., require the shift lever to be in reverse gear to place a backup warning device in the active mode). 2.Allow the driver to reduce detection sensitivity to a restricted limit that minimizes false/nuisance warnings without significantly affecting the target detection capability of the device. 3.Present a warning only after a target or critical situation has been detected as continuously present for some specified minimum time. 4.Mitigate annoyance by allowing the driver to reduce warning intensity or volume. 5.Change modality as the severity of the situation increases (e.g., warn first visually, then add auditory component as severity increases). –Use redundancy across systems (e.g., steering and machine vision inputs to a lane departure warning) to increase the information available to the system and reduce the potential for false alarms. –Use sensors to detect whether or not a driver has already begun to initiate a crash avoidance maneuver. Sensors that detect adjustments to steering, the accelerator, brakes, or other control aspects can be used to reasonably predict a driver's response [see Wilson et al., 6]. Note: While this information reflects the best available evidence for general use, caution is advised when this guidance is applied to the design of heavy-vehicles/buses applications due to differences in driving exposure and operational conditions.

Discussion

False and nuisance alarms can affect both driver acceptance and performance. In Sayer et al. [2], drivers received high rates of nuisance alarms (both visual and auditory) but generally did not consider them to be annoying, in part because they felt that the safety advantages of the system outweighed its shortcomings. Talmadge et al. [3] examined false alarm rates in LCW systems and found drivers did not consider the relatively high rate of false alarms (42 per hour) as annoying. In both studies, the lateral alarms were unobtrusive and visual, and most alarms occurred when drivers would not have noticed them or when they were in a situation where a lane change was unlikely (e.g., in a turn). In Abe and Richardson [7], drivers who experienced late alarms were reluctant to respond to a false alarm; those who experienced early alarms had a delayed response to critical situations when no alarm was presented.

A nuisance alarm rate of less than 0.5 per hundred miles for an FCW ICW system is consistent with the value recommended by Kiefer et al. [1]; this value would result in the average driver receiving a single nuisance alarm per week. Similarly, although more than half of the drivers in Sayer et al. [2] found the nuisance alarm rate of 0.83 per hundred miles of driving to be acceptable, some drivers considered this too high and ignored warnings. With greater daily miles driven, commercial vehicles may require a lower level of false alarms to support driver acceptance.

Design Issues

Nuisance alarms could be reduced by integrating a crash warning system into a larger sensor suite that can assess whether or not a driver has initiated a crash avoidance maneuver [6]. While empirical data regarding their false alarm rate is lacking, emerging technologies such as CV have the potential to reduce false alarms compared with traditional CWSs as there may be more information available to use in determining when to present alerts. Robust CV systems should include mitigations for sources of error such as erroneous or missing GPS signals, communication errors, or other system malfunctions that may potentially result in false or missing alarms. However, the potential benefits of CV technology may still require supplementary sensing for objects that are not part of the CV infrastructure, such as non-CVs, pedestrians, and other objects in the roadway.

Advanced warning system technologies may present issues of perceived reliability, especially if they are able to initiate warnings for hazards that are not immediately visible to the driver (e.g., rear cross-traffic alert or predictive FCW systems). The results from a small-sample simulator study suggest that drivers may have greater trust in systems that provide follow-up feedback when a situation becomes non-critical after the system activates a warning [8]; these results may have limited applicability due to the high degree of participant training and exposure to near-crash events typical of simulator studies. Focus group data [9] show drivers may be more annoyed when given false information about events that require strategic and proactive action (e.g., finding parking, route changes, etc.) as compared to false information that does not have a clear negative impact on the driver (e.g., school zone ahead, severe weather ahead, etc.). Focus group participants [9] indicated high acceptance for imperfect collision warning systems, implying drivers find value in collision warnings but may not fully appreciate diminished performance associated with false alarms.

Horowitz and Dingus [5] provided four concepts for minimizing effects of false alarms: (1) present graded warnings, (2) change modality as severity escalates (e.g., visual CCW then visual-plus-auditory ICW as severity increases), (3) make some settings driver-adjustable, and (4) present headway displays as initial status devices that expand to provide warnings as needed. Forms of these strategies may be appropriate in the design of safety application DVIs.

Cross References

Warning Stages, 4-6

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Multimodal Warning Messages

Introduction

A multimodal warning message consists of more than one type of signal from the visual, haptic, and auditory modalities. The benefits of having multimodal alerts and warnings (versus unimodal) are substantial across a number of different driving scenarios, types of collisions, and driver populations. These benefits include detectability regardless of where drivers are looking (for auditory messages) and having a "back-up" communication channel if there is high ambient noise/vibration (for visual messages). This topic provides information on how to create multimodal messages.

Design Goal: Present simultaneous auditory, haptic, or visual signals to generate a warning message that is quickly and reliably detected and understood by the driver.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • Multiple, simultaneously-activated signals are used to provide redundancy, maximizing the likelihood a driver will receive an alert [1, 2]. • Multiple signals are used to create a sequential change in modality for different stages of a graded system—e.g., less imminent stages of a warning can be represented using a less invasive signal like a static visual icon, and auditory can be used for more imminent alerts [3]. • Non-attention-getting visual components of a multimodal message persist beyond the duration of other warning signals to provide post-alert information regarding the nature of the warning [3].

Example considerations for specific functions of different display types used for a multimodal display.

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; HUD images should not block the drivers view of forward hazards [3].
	High Head-Down Display (HHDD): Used to improve noticeability of the visual aspects of the warning or alert for drivers who are unable to hear or feel the signals from the other modalities that are used [3].
	Low Head-Down Display (LHDD): Used to present visual messages but the presentation period should begin after the warning criterion is no longer exceeded; must be paired with auditory or haptic signals [3].
	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 [4]
Auditory Displays	**Speech Messages:** Speech can also be used to more clearly indicate the nature of the hazard as part of a multimodal display. Speech may lead to better driver compliance with appropriate driving behavior [5] when the imminence of the event is not too severe.
	Simple Tones (Conventional Auditory): Commonly paired with haptic and visual. Spatial messages using simple tones are enhanced greatly when coupled with spatial haptic messages (e.g., Fitch et al., [6]).
Haptic Displays	**Vibrotactile Seat:** Commonly paired with auditory, e.g., the addition of audio or visual displays may facilitate driver comprehension of more complex vibrotactile seat displays.
	Steering Wheel Torques: Commonly paired with a visual and/or auditory display.
	Vibrotactile Steering wheel: Commonly paired with a visual and/or auditory display. Vibrotactile displays are generally rated low in intrusiveness, and are often paired with auditory 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, presenting 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, which is coupled with a visual component (e.g., a tell-tale icon) to convey the nature of the system problem [3]. In addition, there are several usability advantages attached to multimodal displays. Many drivers find multimodal warnings more useful than unimodal warnings [7], and the use of multimodal displays may also help drivers with unisensory deficits (e.g., age-related hearing problems [2]).

Auditory or tactile signals may be used to avoid overloading driver's visual system [8]. Auditory and haptic signals are detectable regardless of where drivers look. Visual warnings can serve as "back-up" communication channels if there is high ambient noise/vibration or if a driver is hearing impaired [3]. Visual warnings serve well as a method for portraying the nature of an alert [3].

Many studies have demonstrated the benefits of multisensory signals when each signal conveys the same information (e.g., [7, 8, 9]). A proof-of-concept evaluation of a multimodal curve speed warning system found compliance was greatest with multimodal displays, with the auditory and visual displays providing clear information about what the driver should do [5]. Likewise, collision avoidance performance for both forward and side object collisions may be best when a bimodal auditory/visual warning system is used, which extends across driving scenarios, types of collisions, and driver populations [2, 10].

Design Issues

Forming a full correspondence between multiple unnatural multisensory stimuli is unlikely to occur without significant training [11]. Therefore, warning signals need to be intuitive and easily learned [7, 8], yet the redundant temporal cues may still be useful when multimodal signals co-occur.

There may be some benefit to a cross-modal paradigm for enhancing responses. For instance, a study in a driving simulator reported by Lerner et al. [13] found that response time is enhanced when there is a verbal or tone-based auditory early-alert that precedes a haptic warning. Despite the observed benefits of multimodal alerts, however, sequential alerts could have some drawbacks. For example, if a driver hears an auditory alert, is responding to that alert, and then sees a redundant visual alert, that redundant visual alert still needs to be processed and thus can in theory increase the time it takes to respond. Lee et al. [9] found that brake reaction time *increased* with a multimodal display. They suggest that performance may degrade when a multimodal warning is perceived as multiple cues, but performance gains can be achieved through matching the characteristics of multi-modal signals in a way that the warning is perceived as a single cue.

Cross References

Developing Driver Training Material, 3-10; Warning Stages, 4-6

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Warning Stages

Introduction

This topic presents information regarding the use of multi-stage graded warnings versus one-stage warnings. Generally, a one-stage warning system provides only an ICW (requires immediate corrective action), while a two-stage system provides a CCW (requires immediate attention and possible corrective action) followed by a separate ICW. A graded warning may include two or more stages of cautionary information that increase in urgency proportionally with the criticality of the hazard situation prior to the presentation of an ICW.

Design Goal: Determine the number of warning stages needed to promote drivers' comprehension of, and response to, the hazard.

Design Guidance

The best available research suggests these heuristics for selecting one- versus multi-stage warnings:

- Consider using a one-stage warning:
  - –For applications in which earlier-stage warnings of a two-stage system may be perceived as nuisance warnings.
  - –If the rate of false alarms associated with a two-stage system significantly reduces driver trust in the system or increases driver frustration with the system.
  - –In potential crash situations that evolve too rapidly for a cautionary warning to be effective (e.g., an FCW cautionary warning that rapidly or ambiguously transitions to an imminent stage).
  - –With ICWs, as a reliable warning presented earlier may be more beneficial for safety than a later warning.
- Consider using a two-stage warning:
  - –When a key goal of the system is to promote a long-term modification of driving behavior.
  - –In situations where hard braking could have an undesirable effect (e.g., lower customer satisfaction in buses and load shifts for heavy vehicles). Hard-braking may be more likely with one-stage systems that only activate for imminent situations.
  - –For alerts related to vehicles in an adjacent lane (i.e., if the visual display is located in the far periphery—such as in the side mirror, on the A-pillar, etc.—when the driver is looking forward). Examples of such applications may include LCW and BSW systems).
- Consider using a multi-stage graded warning system when the primary goal of the system is to provide continuous information (e.g., headway information in an FCW, continuous proximity to vehicle in BSW, LCW, or reverse collision warning (RCW), etc.).

Advantages and disadvantages of using one-stage versus two-stage warnings.

	ICW Only (One-stage)	CCWs + ICW (Two-stage or Graded)
Advantages	• May result in fewer nuisance warnings. • May be simpler for drivers to comprehend. • May avoid confusion arising from rapidly changing warning states.	• May minimize requirements for hard braking (has value for buses and heavy vehicles). • May assist drivers in developing a coherent mental model and better awareness of the CWS device. • May reduce startle effects from ICWs alone. • May aid drivers in maintaining safe headway and in anticipating potential crashes.
Disadvantages	• May provide less time for the driver to recognize and respond to an emerging crash situation.	• May confuse drivers if the alert transitions from CCW to ICW too quickly. • May increase likelihood of real or perceived false alarms. • May reduce driver trust and use of the system due to false alarms.

Discussion

Single-stage warnings have some reported benefits. Kiefer et al. [1] found that a single-stage FCW was more effective under distracted-driver conditions than two-stage warnings with a visual-only CCW [1]. Furthermore, Kiefer et al. [2] note that a one-stage warning is the preferable warning configuration for the following reasons: (1) better driver acceptance because of fewer nuisance alarms, (2) better compatibility with more effective warning algorithms, (3) provides a simpler mental model for drivers to comprehend, and (4) avoids the potential ineffectiveness of—and driver confusion arising from—cautionary warning alerts because the CCW stage is very brief in practice. With the increase in applications potentially available through CV technology, the use of single-stage warnings can minimize drivers' exposure to too many warning signals in systems with many integrated applications.

Other research shows benefits from two-stage warnings in similar driving situations [3-7], and most sources recommend two-stage warnings. Graded warnings may aid drivers by priming their responses to the ICW [3]. Two-stage warnings may be more appropriate in situations other than FCW, such as LCW and LDW, and with heavy vehicles because of different situational factors that increase the utility of cautionary warning information [8, 9]. Lerner, Kotwal, Lyons, & Gardner-Bonneau [4] notes that: (1) CCWs assist drivers in developing a mental model of the system, (2) they may reduce ICW startle effects, and (3) because true ICWs are relatively rare, the CCWs help keep drivers aware of the FCW system. Another option examined in the literature is a five-stage looming display for FCW that indicates: (1) no vehicle detected, (2) vehicle detected, (3) caution, (4) approaching imminent, and (5) imminent [5].

Design Issues

Selection of one- versus two-stage warning should include careful consideration of the display features and modality selected for each stage. For example, driving simulator research by Lerner et al. [8] found that responses to tone-based alerts were faster when an early verbal-auditory alert was provided, but slower when the early alert was tone-based. They also found that responses to a haptic warning were enhanced by early-alerts that were verbal or tone-based. Research in single-stage warnings has indicated that earlier warnings are beneficial and that late warnings may not be as effective [9]. Additionally, other research suggests that if graded warnings are used, the transition from CCW to ICW must be clear and unambiguous [4].

The timing of warning stages is important. If the CCW is presented too late, drivers may not have time to understand the rapidly evolving hazard situation and become confused by the rapid change from CCW to ICW [2]; however, if the CCW is presented too early, drivers may perceive the alert to be a false alarm and distrust the system or possibly delay responses to the subsequent ICW.

Two-stage warnings for LDW or BSW systems may be particularly useful when the visual displays are located in the side mirrors or A-pillar as they are generally available only when the driver is looking for information from them (i.e., checking the mirrors before a lane change). In these situations, the CCW visual signals will most likely not be considered a nuisance, and they could provide sufficient advance information of a potential threat that an ICW is not necessary.

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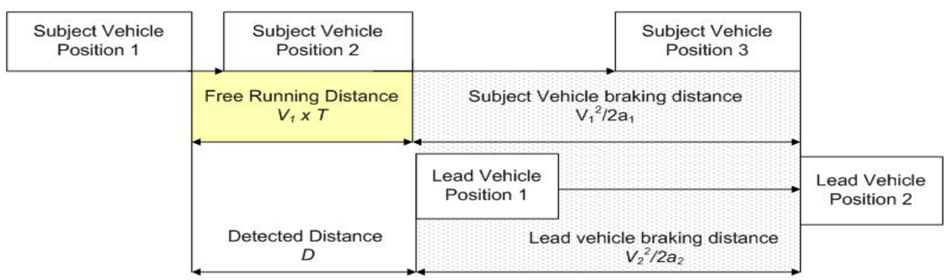
Providing Forward Collision Warnings that Accommodate Driver Brake Reaction Time

Introduction

This topic describes the different elements of a brake reaction time relevant to FCWs and provides general design information and key research findings relevant to the timing of warnings. Driver brake reaction time is the key human factors element to the Basic Equation of Collision Warning in ISO 15623 [1].

Design Goal: Provide a forward collision warning that accommodates drivers' *brake reaction time*.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • Estimates of stopping time to forward hazards includes perception-response time, the time it takes a driver to remove their foot from the accelerator pedal and apply it to the brake pedal, and the amount of time it takes to fully depress the brake [2]. • FCWs are issued early enough so that there is time to allow drivers to determine how to respond, depress the brake pedal and slow the momentum of the vehicle [3]. • The timing of the alert is no later than the driver's unassisted accelerator release; this may enhance driver trust for FCWs [4]. Warning algorithms that use lower required driver deceleration levels (e.g., $a_1 = 0.35$ g) are associated with greater trust ratings compared to those that use greater values (e.g., $a_1 = 0.75$ g) [4].

The basic equation of a forward collision warning system [1].



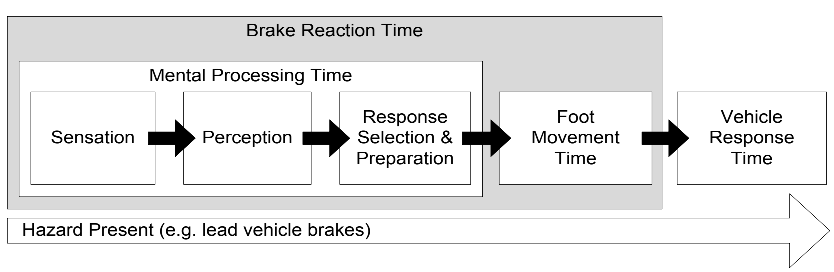
Basic Equation: $D = V_1 \times T + (V_1^2/2a_1 - V_2^2/2a_2)$

Where:

D is the distance to the preceding obstacle;
V_1 is the speed of the subject vehicle;
V_2 is the speed of the lead vehicle;
T is the reaction time of the subject vehicle driver;
a_1 is the deceleration of the subject vehicle;
a_2 is the deceleration of the lead vehicle.

This excerpt is adapted from ISO 15623:2013, Figure A.1 on page 18,
with the permission of ANSI on behalf of ISO.

Stopping time model: Driver and vehicle aspects.



Discussion

ISO 15623 [1] provides a basic equation for the timing of an FCW, including a parameter called free running distance (top figure on page 4-8) that is the product of driver brake reaction time (grayed area in bottom figure on page 4-8) and vehicle speed (representing the distance traveled between event onset and brake application).” In addition to driver brake reaction time, ISO 15623 indicates that there should be a minimum of 0.8 seconds for the driver to respond to the alert, with the implemented value for driver brake reaction time as a design parameter to be determined by the manufacturer. While ISO 15623 provides some limited information on driver brake reaction time, additional research provides a convincing argument against the use of a canonical value for driver brake reaction time to forward events [2, 5, 6, 7]. However, the research is less conclusive about values associated with contributing factors.

Stopping time is comprised of several components: the *mental processing time* (how long it takes the driver to sense, perceive, and decide upon a reaction), the *movement time* (how long it takes the driver to physically activate the brake pedal), and the *vehicle response time* (how long it takes the vehicle’s braking system to engage and bring the vehicle to a stop) [6]. The first two components, mental processing time and movement time, may be referred to as brake reaction time and are subject to individual differences. The last component, vehicle response time, is a function of the vehicle engineering, however the driver’s ability to effectively actuate the brakes and slow or stop the vehicle in panic situations is highly variable and typically below the vehicle braking system’s optimal abilities [8].

With respect to the DVI for a CWS, the first two components (mental processing time and movement time) are critical in terms of a CWS’s DVI design. Both the potential range of driver characteristics, as well as the current state of the driver, may be considered in designing an optimal warning interface. Driver reaction time is highly variable. Laboratory and test track studies have found effects of expectancy, driving experience, age, cognitive and visual load [2, 9], arousal and fatigue, and urgency [5] on brake reaction time. Naturalistic driving data suggests the presence of significant effects of eyes off road time, age, weather, traffic density, and lighting conditions upon brake reaction time [7]. Taken as a whole, the research suggests that expectancy, experience, arousal, and situational urgency generally reduce brake reaction time, while increasing age, cognitive and visual loading, lower levels of arousal or fatigue, increased eyes off road time, poorer weather conditions, heavy traffic density, and poor lighting conditions are associated with increased brake reaction time. Values from research [2] indicate that a primed (expectant of the cue) driver under optimal conditions may have a brake reaction time of under 1 s, while analysis of naturalistic data [7] suggest that brake reaction time could range from 1.5 s to 2.5 s (and occasionally greater depending on driver state, such as distraction). However, as mentioned above, the lack of consensus within the research precludes the use of a canonical value for driver brake reaction time.

Design Issues

Simulator research [10] shows that longer or shorter warning timing may affect driving differently. Over 3 days of testing early and later warnings warnings (i.e., 3.2 s and 2.2 s time-to-collision (TTC)), only early warnings lead to a headway buffer that was substantially different from the warning timing (i.e., on the 3rd day of testing, median headway was 4.5 s when the warning was early, and 2.5 s when it was late). Early warnings occur when there is more distance between vehicles and are thus more likely to activate compared to later warnings. In this study [10], drivers with the early alert that increased their headway also substantially reduced the frequency of alerts over time.

DSRC messages can have latencies with durations up to 1000 ms that may lead to communicating invalid positional information [11]. Whatever the specific latency of a system, this latency will need to be incorporated into the algorithms used to issue a warning.

Cross References

False and Nuisance Warnings, 4-2; Warning Stages, 4-6

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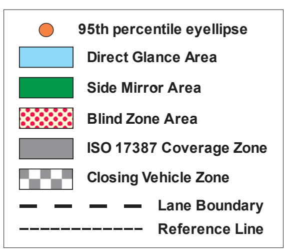
Using Coverage Zones to Provide Lane Change Information

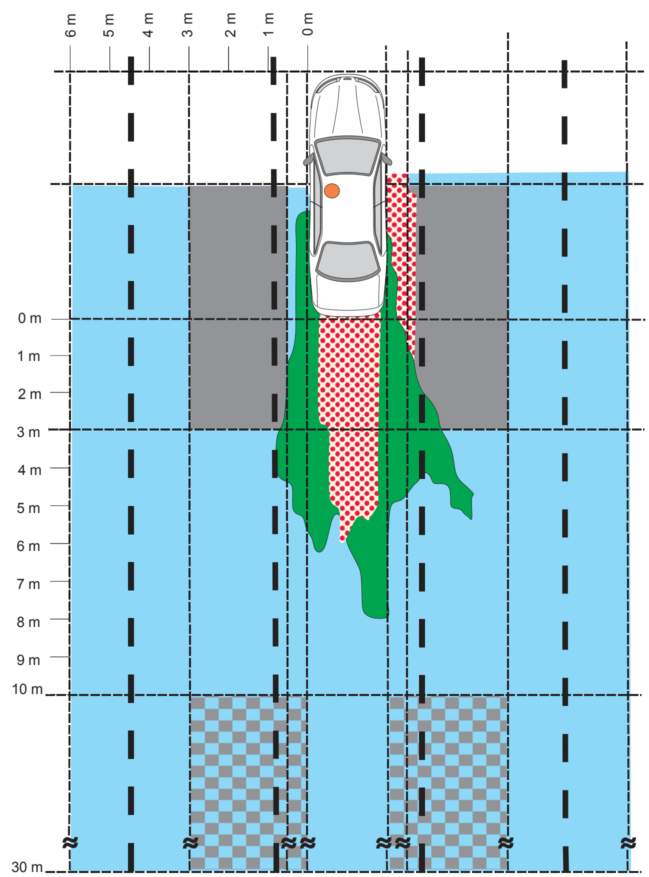
Introduction

Standards for lane change assistance systems (e.g., ISO [1], SAE [2]) contain specific dimensions for adjacent-vehicle detection coverage zones that surround the driver's vehicle. Some dimensions are advised to be relative to specific vehicle and driver variables (e.g., coverage zones typically extend rearward from the position to the 95th percentile eyellipse, to 3 m behind the vehicle). This topic contains information on how to consider driver and vehicle variables for determining when to provide information to support lane change decisions.

Design Goal: Activate a lane change collision avoidance message when other vehicles enter the driver's blind zone area.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • Systems deliver a blind spot message when vehicles enter the coverage zones (blind zone area below) that extend from the side and rear of the vehicle. • Systems determine the driver's intention to change lanes. This can be accomplished by assessing turn signal status, steering input, or lane position [1]; patterns of surrounding traffic (e.g., evaluating gaps between adjacent vehicles and forward headway) relative to the driver's speed [3] or driver gaze [4]. • Warnings may be suppressed when the driver is overtaking a lead vehicle [1]. Drivers may be aware of vehicles they are passing when they are intentionally overtaking a lead vehicle. This is optional in the ISO standard [1].

ISO/SAE lane change decision assist system hazard detection coverage zones.
Zones are superimposed on data from a Visibility Assessment.





Eyellipse: Location of the 95th percentile viewing position.
Glance Area: Location visible using direct glances.
Side Mirror Area: Location not visible with direct glances but visible through the mirror.
Blind Zone Area: Location not visible using a glance or through the mirror.
Coverage Zone: ISO-SAE Adjacent Blind Spot Zone (ABSZ) requirement.
Closing Vehicle Zone: ISO classification for detection of a rear closing vehicle.
Lane Boundary: Lane delineations, which are typically 3-4 m wide.
Reference Line: Used to denote additional considerations for coverage zones.
Note: Glance Area, Side Mirror Area and Blind Zone Area were based on visibility measurements from a 2007 sedan and the seated position of a 50th percentile male driver [5] but the scale in this diagram is only approximate. See Discussion.
Diagram based on ISO 17387 [1], SAE J2802 [2], and Mazzae & Garrott [5]. This excerpt is adapted from ISO 17387:2008, Figure 10 on page 11, with the permission of ANSI on behalf of ISO.

Discussion

The purpose of the diagram for this topic is to demonstrate the extent that standardized blind-spot warning zones match up with actual measurements of driver visibility of the sides and rear areas of a vehicle.

Importantly, the dimensions of the blind zone areas and side mirror and direct glance areas (see figure on previous page) are specific to vehicle and driver dimensions and will vary across vehicle types and drivers. For example, for 50th percentile height male drivers the blind zone extending from the rear of a 2007 Honda Accord extends for 6 m, whereas the blind zone for a 2005 Chevrolet Silverado HD2500 extends for 12 m, but for 5th percentile height female drivers these blind zones extend for 5 m and 10 m, respectively [5]. The extent to which lane change assistance systems should correspond to driver visibility areas is a design issue that has not been addressed sufficiently in the literature. Driver perception of the reliability of blind-spot warnings may have a high correspondence with how well drivers are able to view surrounding traffic, but this claim lacks empirical support.

Although there is no mention of the visibility areas around a vehicle within standards documents, if a system can deliver lane change messages when vehicles enter the blind zone area in the coverage zone diagram, then the system meets ISO/SAE standards for a Blind Spot Monitoring system. If the system can provide additional information about surrounding traffic that is farther away then there are options to classify the system as capable of providing additional lane change messages (e.g., a closing vehicle warning can be issued when an approaching vehicle is detected within the closing vehicle zones and time to collision is between 2.5-3.5 s).

There are methods to determine the driver's intent to change lanes as indicated within the ISO international standard (e.g., monitor turn signal status, steering input, or vehicle lane position [1]). The use of turn signal status to evaluate driver intent to change lanes may be problematic for two reasons: (1) drivers use turn signals to indicate the intent to make a lane change but also (2) to indicate the execution of a lane change [6]. Drivers might use turn signals to indicate the execution of a lane change at any point between just after their initial intention, through the mid-point of the maneuver after already entering the adjacent lane, and up until nearly completing the full lane change. Alternatively, a system architecture has been developed that addresses the entire lane change maneuver (e.g., identifies when a lane merger may occur due to lead vehicle proximity and current velocity or acceleration, identifies adequate gaps in traffic, etc.). A system under this architecture would assist the driver from the first intention through the movements to the final lane change [4]. Gross measures of driver glance behavior may also serve as a measure of intent. Although, drivers tend to spend most of their time glancing forward (e.g., 69.2% during the latency period before merging left) they make significant changes to how often they view their left mirror (e.g., 2.1% when not changing lanes to 9.2% of glance time before changing lanes [7]).

Design Issues

The visibility areas in the diagram were obtained from a test procedure with a seated driver (e.g., 50th percentile male) who was asked to indicate where a 60 cm test cylinder was visible as it was placed at various locations around test vehicles [5]. A factor limiting the generalizability of the results stems from the test procedure's consisting of the use of a small object to measure visibility areas around vehicles. A method to determine the visibility zones for detecting objects as large as vehicles needs to be established, and additional human factors elements need to be included in assessments of the functional aspects of the visibility area (i.e., what happens to these visibility areas during collision-probable scenarios?).

Cross References

Using Localization Cue to Indicate Direction, 7-12; Presenting Spatial Information Using a Vibrotactile Seat, 8-14

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7. Olsen, E. C. B. (2004). Lane change warning design guidelines. *Proceedings of the 48th Human Factors and Ergonomics Society Annual Meeting¸* 2237-2241.

Chapter 5. 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, drivers need to respond quickly, at a time when the driving situation could potentially require high cognitive demand. Messages that are presented under these conditions must: capture drivers' attention without being distracting, be 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 collision warning applications, it is expected that non-critical messages may also be presented on integrated displays. Commercial vehicle fleets may integrate productivity and mobility applications into a central display, and central displays in passenger vehicles may include integrated "infotainment" and navigation applications. The information in this chapter discuss the issues associated with DVI messages and how to present them in a way that will enhance safety, optimize responses, and minimize distraction.

Topics included in this chapter:

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

Designing Messages for Driver Comprehension

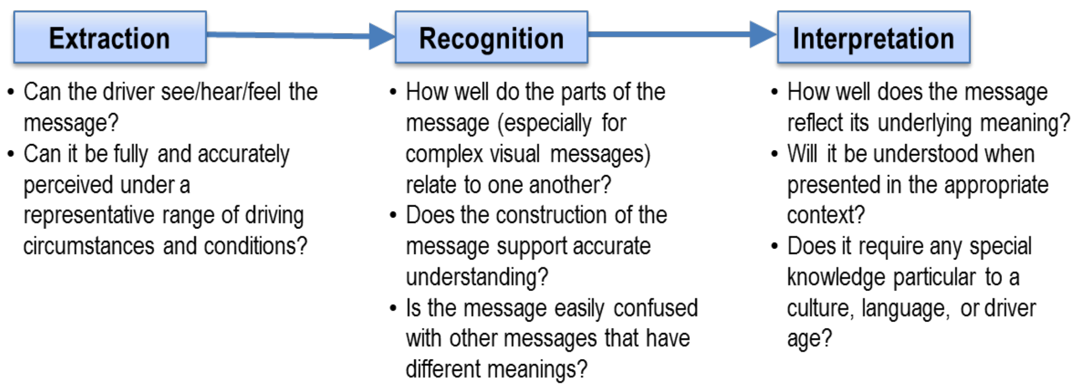
Introduction

This topic provides design 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. Drivers' ability to correctly and quickly respond to time-critical messages largely depends on how rapidly they comprehend the meaning of the message. Broader conceptual frameworks that address the comprehension of in-vehicle messages are scarce, but such a process is described by Campbell et al. [1] for icon/symbol comprehension, and serves as the foundation for this topic.

Design Goal: Develop and present messages in a manner that supports accurate and timely comprehension by the driver.

Design Guidance

There are three stages associated with message comprehension: extraction, recognition, and interpretation [1]. 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 and 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 et al. [1], 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. For example, the message must be presented within the normal range of human perception—a very high frequency auditory message may not be heard by the driver. 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 [2].

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' expectations and experience, memory limits, and workload. Familiarity in particular has been found to be strongly associated with comprehension. A study reported by NHTSA [3] found that drivers responded more slowly to a driving event (e.g., forward collision event) when they experienced an unfamiliar auditory alert after previously becoming familiar with a different alert. Similarly, naïve drivers had difficulty comprehending advanced collision warning system (ACWS) messages about ACWS presence and status, even after reading the user manual. Also, in a driving simulator, Vernet and Fraigneau [4] found that when drivers experienced collision warnings while driving under varying levels of task complexity, one of the key factors that affected response time to collision warning signals was familiarity with the warnings. In short, after exposure and extended use, drivers can learn to comprehend virtually any message. However, while even "bad" messages can eventually be effective, they may initially 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. Overall, a rigorous and iterative evaluation process will increase the likelihood that the implementation of the message will improve overall safety, and not detract from it. A number of procedures can be used to measure driver comprehension of messages, including SAE J2830, *Process for Comprehension Testing of In-vehicle Icons* (focused on icons or symbols) [5]. 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 [6] 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, 3-10; Message Complexity, 5-4

Topic References

1. Campbell, J. L., Richman, J. B., Carney, C., & Lee, J. D. (2004). *In-vehicle display icons and other information elements, Volume I: Guidelines* (Report No. FHWA-RD-03-065). Washington, DC: Federal Highway Administration.
2. Alliance of Automobile Manufacturers. (2006). *Statement of principles, criteria and verification procedures on driver interactions with advanced in-vehicle information and communication systems, including 2006 updated sections* (Report of the Driver Focus-Telematics Working Group). Available at www.autoalliance.org/index.cfm?objectid=D6819130-B985-11E1-9E4C000C296BA163
3. National Highway Traffic Safety Administration (NHTSA). (2011a). *Crash warning interface metrics, phase 2* (Report No. DOT HS 811 471). Washington, DC: Author. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811471.pdf
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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. 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.

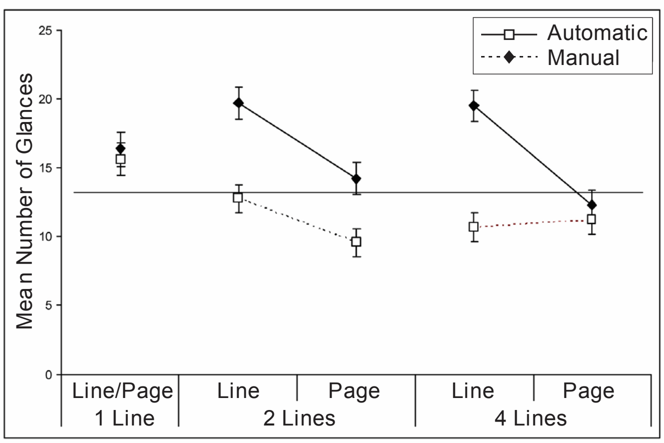
Design Goal: Present messages to the driver in the simplest form possible so the driver can readily perceive, comprehend, and act upon the information.

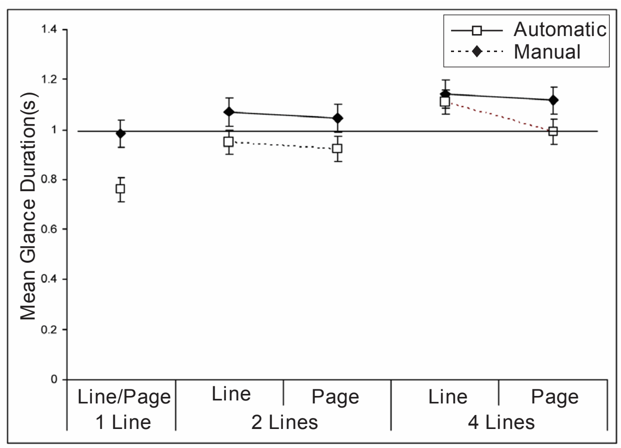
Design Guidance

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 [1].





Figures recreated from Hoffman, J., J. Lee, D. McGehee, M. Marcias, and A. Gellatly. 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, D. C., 2005. Reproduced with permission of the Transportation Research Board [1].

"Automatic" and "Manual" refers to whether the text on the page was scrolled manually by the participant or automatically. On the "X" axes of the figures above, the lines/page variable defines the amount of text visible to the drivers at any time; 1, 2, or 4 lines.

Discussion

Complexity in DVI messages generally refers to the amount of information provided in the message, but also includes consideration of how the information will be used by the driver and 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, 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. [1], 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 with 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 [2], 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 et al. [3] and Easterby [4]). 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 [5].

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 [6].

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, and Gardner-Bonneau [7]).

Design Issues

Inadvertent increases in message complexity can occur in the vehicle environment as multiple applications and subsystems are added to the vehicle 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 [8] discusses the problem of "complexity creep", referring to the practice of adding features and capabilities over time to systems, and how such practices can increase complexity may reduce the interpretability of information, reduce the predictability of the system, and slow response time.

Cross References

Designing Messages for Driver Comprehension, 5-2; Selecting Character Height for Icons and Text, 6-8; Tutorial 1: Procedures for Assessing Driver Performance: Visual Demand Measurement

Topic References

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5. Rayner; K.; Pollatsek, J.; Alexander, B. (2005). *Eye movements during reading.* In M. J. Snowling & C. Hulme (Eds.), *The Science of Reading: A Handbook* (pp. 79–97). Oxford, UK: Blackwell Publishing. doi: 10.1002/9780470757642.ch5
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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. The mode of warning presentations in particular 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, etc.), the criticality of the message (e.g., hazard versus non-hazard situations), location of visual displays, and other factors. 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 (see also Chapter (8). This topic provides information that will help designers determine which presentation modes are most appropriate for various messages.

Design Goal: Match the modality of messages with driver tasks, needs, and expectations in order to enhance drivers' comprehension and performance.

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 (uninterrupted presentation of information over a trip segment, a trip, or even a longer period of time) lower-priority information such as 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 a primary auditory or haptic message.
- Provide primary warning information in a situation in which drivers can reasonably be expected to see the visual warning as part of the regular information-acquisition process (e.g., a visual imminent crash warning for an LCW system that is presented on the rear-view and side-view mirror, or on an A-pillar).

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., imminent collision warnings); in this instance, can be used in conjunction with visual (or haptic) messages to provide redundant cues to the driver.
- 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).
- Draw attention directly to the location of a potential crash threat.
- Indicate the onset of a system malfunction or limitation.
- Augment a visual warning in a non-time-critical situation.

Haptic messages are capable of quickly capturing the driver's attention and can be used if:
- An auditory message is unlikely to be effective (e.g., if the driver's auditory workload is excessive, if auditory warnings are used extensively in another CWS device, or if ambient noise is too high).
- It is likely that the driver is in contact with the haptic feedback source (e.g., drivers will usually feel a seat vibration but they may not feel accelerator pedal feedback).

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 [1], who laid out a series of useful rules for assisting designers in this task. The table below lists Deatherage's original eight rules providing guidance for the selection of auditory and visual mode presentations.

General rules for selecting auditory versus visual display modes [1].

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.

For presenting warnings or alerts, most sources concur with Lerner, Kotwal, Lyons, and Gardner-Bonneau [2] that auditory messages should be reserved for high-priority messages only and should be the primary warning modality. The advantage of auditory warnings is that they can command attention regardless of where the driver is looking. In a series of closed-track Crash Avoidance Metrics Partnership studies [3], naïve drivers that were intentionally distracted prior to a surprise braking event reported noticing the auditory component of a multimodal warning much more often than the visual component (i.e., 99 % versus 17-50 %). Based on the full set of results from this research, the authors recommended using a multimodal auditory and visual ICW for FCW systems. They also recommended that if only a single-modality display was implemented in a FCW system, that it should use an auditory warning signal.

Design Issues

Most of the relevant literature [3, 4, 5] suggests that operator performance can be improved by combining auditory and visual messages when presenting warnings. In addition to the above, Williges and Williges [6] 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.

As noted above, while visual messages are generally best for presenting non-critical information or for augmenting an auditory warning, HUDs and HHDDs (i.e., located on the dashboard) also have potential for presenting critical information, especially if the message has a spatial component.

Cross References

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

Topic References

1. Deatherage, B. H. (1972). Auditory and other sensory forms of information presentation. In H. P. Van Cott & R. G. Kinkade (Eds.), *Human engineering guide to equipment design* (rev. ed.) (pp. 123-160). Washington, DC: U. S. Government Printing Office.
2. Lerner, N. D., Kotwal, B. M., Lyons, R. D., & Gardner-Bonneau, D. J. (1996, January). *Preliminary human factors guidelines for crash avoidance warning devices* (Report No. DOT HS 808 342). Washington, DC: National Highway Traffic Safety Administration.
3. Kiefer, R., LeBlanc, D., Palmer, M., Salinger, J., Deering, R., & Shulman, M. (1999). *Development and validation of functional definitions and evaluation procedures for collision warning/avoidance systems* (Report No. DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.
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5. Campbell, J. L., Richman, J. B., Carney, C., & Lee, J. D. (2004). *In-vehicle display icons and other information elements, Volume I: Guidelines* (Report No. FHWA-RD-03-065). Washington, DC: Federal Highway Administration.
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Chapter 6. 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 involving semantic content that benefits from persistence, as distinct from auditory linguistic warnings, which tend to be obtrusive if they persist[1].

While vision provides a rich field for information coding and providing potentially complex messages that can help interpret warnings, 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 (HUDs) 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.

Topics addressed in this chapter:

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

[1] See Chapter 5, *Selection of Sensory Modality,* for information that will help determine if a visual display is appropriate for a particular warning message.

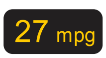
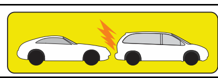
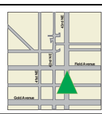
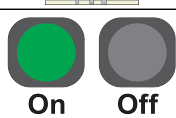
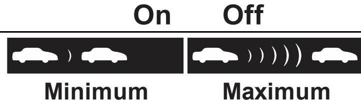
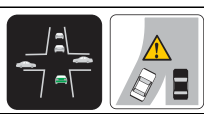
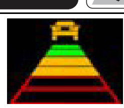
Visual Display Type for Safety-related Messages

Introduction

Visual displays can be used to convey warnings or other information. There is a large range of potential information that can be conveyed, including safety warnings related to other vehicle positions or states, road hazards such as impending curves or merge situations, and driving performance such as fuel efficiency. This topic focuses on safety warning messages related to external and internal vehicle state information (e.g., adaptive cruise control status), and updates and expands the information presented in Campbell et al. [1]. Display type refers to the general format of the presentation (e.g., digital, analog, text, etc.), as distinct from the specific implementation hardware (such as HUDs or high head-down displays [HHDDs]) and location.

Design Goal: Select visual displays that convey information in a way that is consistent with the functional requirements of the application.
Design Guidance
The research suggests that these visual display factors may be manipulated or used in support of the design goal: • Continuous or graded analog displays with scale information (sometimes known as "looming displays") are appropriate to convey crash warning information or headway information at increasing levels of criticality. • Symbolic or iconic representations can be used to add meaning to critical analog displays and do not require reading to interpret. • Spatial information is appropriate for showing intersection and lane change or merge warnings. • Representational displays can be used to provide the driver with information regarding the functional status of vehicle systems or states, relative to current conditions.

Examples of visual displays.

Visual Appearance	Display Type	Explanation	Class of Information
	Digital	Conveys information with specific numeric or status values	Specific Value
	Text	Vehicle status requiring verbal interpretation	Verbal Meaning
	Icon or picture	Simple graphic requires no verbal interpretation	Symbolic Meaning
 *	Icon or picture with text	Simple graphic enhanced with short text requiring interpretation	Symbolic and Verbal Meaning
	Map	Conveys information about location of own vehicle and other traffic	Spatial
	Digital	Conveys binary status information about whether a condition or state is true/active	Device State: Presence or Absence
 **	Functional	Conveys mode of operation and status to aid driver interpretation	Device State
	Representational	Conveys location and/or spatial information about surroundings	Spatial
 **	Continuous or Graded (Analog)	Conveys information on continuous scale to show change and rate (looming display)	Trend

* Adapted from Campbell et al. [1]   ** Adapted from General Motors/Delphi [2]

Discussion

Display types for safety-related systems should be selected based on the need for conveying specific information to the driver. In particular, display types should be consistent with the type of information being communicated, the manner in which drivers think about and use the information and—if appropriate—the nature of the driver response associated with the message. This reflects an information processing principle called stimulus-response compatibility in which more compatible mappings between displays and their desired response require fewer mental operations from display to response [3] than less compatible displays. Overall, highly compatible display-response relationships can lead to the development of a strong mental model of the system by the operator, as well as reduced response times and fewer errors in responses than non-compatible display-response relationships. A simple example includes use of a red indicator mounted on the left A-pillar that flashes when the driver activates the left turn signal or begins a lane change when a vehicle is located in the driver's left blind spot. Red is a stereotypical color that is accepted to indicate danger, with flashing that indicates urgency. The leftward orientation of the indicator corresponds with the activation of the left turn signal and indicates that the hazard is on the left side of the vehicle. These stimulus characteristics are designed to elicit a response to abandon the lane change maneuver (i.e., steer away from danger).

There are few stand-alone studies of visual display types—they are generally evaluated in combination with other alerting warning signals such as auditory or haptic. Moreover, there are very few in-depth and systematic investigations exploring which display types are best for specific types of information. Current research about the suitability of some display types is summarized below:

- *Continuous or Graded Displays*: Existing evidence suggests that graded-scale ("looming") displays are acceptable for imminent forward crash warnings (FCWs) [2] and lengthening headway [4].
- *Representational Displays*: Hatakenaka et al. [5] showed that drivers prefer a more realistic representational map over a standard merge sign icon to provide merge warnings. Stanton et al. [6] showed that drivers preferred and were better able to comprehend system state and detect adaptive cruise control (ACC) targets with a radar-type display, despite being rated higher on mental workload.
- *Icon Displays*: Thoma et al. [7] showed that specific icon-based warnings facilitated comprehension in difficult-to-detect visual scenes.

Design Issues

The functional purpose of information presentation should be the primary criterion for selecting the visual display type. Continuous displays such as looming headway or safe speed indicators can be used for behavior modification, although there is potential for driver distraction with an "always-on" and regularly changing display. For imminent warnings such as lane change, intersection assist, and emergency braking, driver preference and limited performance data indicate that spatial and graphically explicit representations are best. Forward collision warnings can be presented on looming displays, and existing data suggest that simple head-up presentation is most appropriate (see Head-up Displays, 6-16). With increasing use of driver-aiding technologies, use of representational displays to convey system state will be important to alert drivers to situations where intervention with the automated system may be required. A balance must be adopted between display content, interpretability, and frequency of occurrence.

Cross References

Designing Messages for Driver Comprehension, 5-2; Locating a Visual Display, 6-5; Using Color, 6-7; Temporal Characteristics of Visual Displays, 6-13; Head-up Displays, 6-16

Topic References

1. Campbell, J. L., Richard, C. M., Brown, J. L., & McCallum, M. (2007). *Crash warning system interfaces: Human factors insights and lessons learned, final report* (Report No. DOT HS 810 697). Washington, DC: National Highway Traffic Safety Administration.
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Locating a Visual Display

Introduction

The location of a visual display is a key factor affecting the ease with which drivers can obtain information. Traditional dashboard designs are changing as new warning and information systems become available; appropriate placement of the visual component of these systems will facilitate access to the information while reducing the impact on the driving task. The main focus of this topic is the location of the display or displayed information on other surfaces (such as mirrors), and minimizing the impact of glare to ensure readability.

Design Goal: 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.

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 located within ± 15 degrees of the central line of sight but as close to the central line of sight as practicable. Messages that require immediate detection should be located within 5 degrees of the forward view when possible [1], and 5 degrees to the right and 5 degrees down for messages on a HUD [2].

Ⓑ –Displays are placed in locations that are generally compatible with established expectations or with location cues from other warnings, such as auditory or haptic.

Ⓒ –The display location is compatible with the desired response, such as a display in the mirror for alerts for looking to the blind spot; a HUD that is used to direct attention to the forward view for critical warnings.

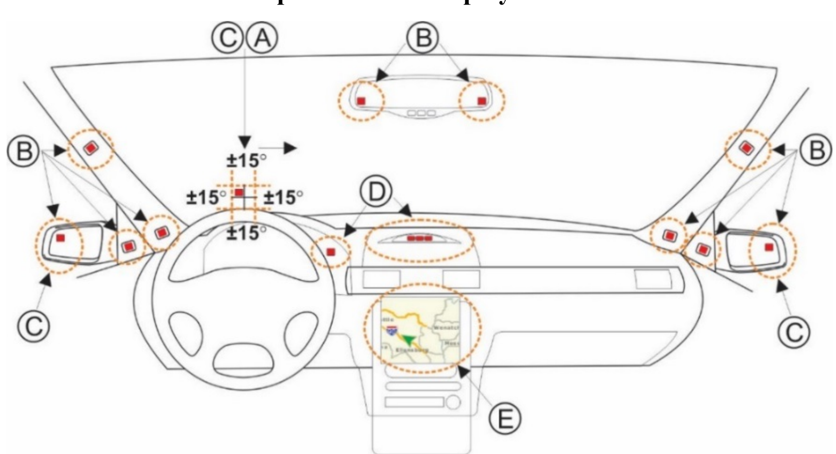
Ⓓ –The design and location minimizes glare from external sources or other displays in the vehicle (e.g., in the instrument panel or under a protective cover).

Ⓔ –All messages or content presented on reconfigurable or multipurpose displays should be consistent with the above design guidance. Specifically, both content and device location should be mutually compatible with line of site, driver expectations, and response compatibility for all warning messages presented on the display.

The figure below shows examples of somepotential visual display locations that correspond with the design information given above. The circled letters in the diagram point to the elements that illustrate each concept in the design guidance above. Following are additional notes regarding the individual elements in the figure:

- ⒷⒸ Displays located on the side mirrors and A-pillars provide information that is easily detected when checking the mirrors or looking to the sides. Examples of applications that might use such displays include Blind Spot Warning (BSW), Lane Change Warning (LCW), or Intersection Movement Assist (IMA).
- Ⓑ Displays located in either corner of the rear-view mirror provide warning information to drivers who begin a lane change maneuver by first checking the rear-view mirror.
- ⒶⒸ Warnings presented on a HUD provide information about hazards directly ahead. The symbols on the HUD are within ±15° for rapid detection.
- Ⓓ Displays are shielded from glare by locating the display under a cowling.
- Ⓔ Safety information presented on a multi-function display is appropriate for the display location. Both content and location mutually support timely and accurate responses to associated hazards.

Examples of visual display locations.



Discussion

In general, locating the visual warning near the line of sight to the primary driving task will increase the likelihood that it will be seen and will reduce the time needed to glance at that information [3]. An FCW, or other forward-oriented warning, will be most effective when it is near the line of direct forward gaze toward the road ahead. Similarly, an LCW or BSW will be more likely seen when it is near the line of sight to the side mirror as the driver checks the mirror before initiating the lane-change maneuver. The Lerner, Kotwal, Lyons, and Gardner-Bonneau preliminary guidelines [4] recommend that displays for non-directional hazards (e.g., low road friction) should be located within 15 degrees of the driver's line of sight of the roadway ahead, while ISO [1] recommends that critical visual messages that require immediate detection should be located within 5 degrees of the driver's line of sight. ISO [5] also recommends that critical visual signals should be located as near to the driver's line of sight as possible, particularly if color is used. Color affects peripheral detection: green objects are not detected beyond 15 degrees from the line of sight, while red and yellow/blue are not detected beyond 18 and 22 degrees, respectively. These findings further support the recommendation that warning displays should not exceed 15 degrees of eccentricity.

Lerner, Kotwal, Lyons, and Gardner-Bonneau [4] recommends that the visual display should be located such that it draws the driver's gaze toward the hazard. They also recommend that a warning should induce an orienting response that is compatible with the desired driver action and, importantly, that care should be taken to avoid eliciting a response that is inconsistent with the desired driver action. This reflects an information processing principle called stimulus-response compatibility in which more compatible mappings between displays and their desired response require fewer mental operations from display to response [6] than do less compatible displays. Wege et al. [7] provide information concerning driver glance changes in response to forward collision warnings; in particular, this group found that forward glances were increased in response to warnings. Overall, highly compatible display-response relationships can lead to the development of a strong mental model of the system by the operator, as well as reduced response times and fewer errors in responses than non-compatible display-response relationships.

Design Issues

It can be generally assumed that drivers will expect key visual information to be presented in the general vicinity of the instrument panel. Traditional vehicle health and status warning light displays tend to be placed in the instrument panel. Location of directionally-specific warnings should correspond to the hazard, such that blind spot warnings might be placed on either side mirror; similarly, intersection warnings may be directionally placed either on the A-pillars with directional indications in the cluster or other selected location (e.g., HUD, HHDD). Side mirror placement of warning information needs to accommodate likely glare issues; use of multiple element displays or flashing provides a design approach to this issue.

Research [2] suggesting enhanced perception and preference for display locations 5 degrees below and to the right of the central forward gaze suggests a potential standard location for HUD warning messages, should manufacturers wish to converge on a standard. The tendency of drivers to seek information *following* a critical, unpredictable event, despite the absence of displayed information, suggests that such displays be as close to the central gaze area as possible. The finding also suggests that designers minimize the display of complex traffic or device state information, as frequent use of these displays may alter driver glance patterns in undesirable ways.

Cross References

Multimodal Warning Messages, 4-4

Topic References

1. International Organization for Standardization. (1984). *Development and principles for application of public information symbols.* (ISO/TR 7239). Geneva: Author.
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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.

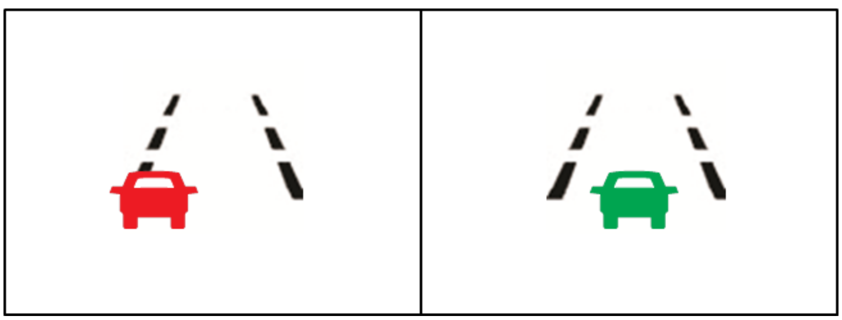
Design Goal: Use color to augment visual information presented in the displays to attract attention and/or to convey the urgency of conditions or situations.

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 minimized; do not exceed 4 color codes.
- Color is used to create a "popout" 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 the two-stages of a warning display using color.



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 warning signals or symbols 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 [1]. While there have been some recent findings that the association of red with “danger” is stronger than the association of yellow with “caution” [2], 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 [3] 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 CCW visual warning (however, see Design Issues below). The color green should not be used as a CCW because it is associated with safe or normal operating conditions [1].

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 [4], and application of these conventions for future safety system messages (e.g., CV safety messages) is appropriate. Color-shape combinations can increase reaction times when signs use 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 [5]. Designers should avoid incompatible or unconventional shape and color combinations, such as octagonal shape (having a conventional meaning of stop) presented with a yellow background (having a conventional meaning of 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 [1]. For messages requiring the presentation of text, green text has the advantage of being at the frequency of maximum spectral sensitivity of the eye [6]. 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 [1].

Cross References
Designing Messages for Driver Comprehension, 5-2; Locating a Visual Display, 6-4

Topic References

1. International Organization for Standardization. (2005). *Road vehicles—Ergonomic aspects of in-vehicle presentation for transport information and control systems—Warning systems* (ISO/TR 16352). Geneva: Author.
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Selecting Character Height for Icons and Text

Introduction

Text and graphic symbols in the driver-vehicle interface must be legible by all drivers 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. This topic addresses character height: including the visual angles subtended by the icon, its graphical elements, text within the icon, and free-standing text.

Design Goal: Select sizes for text and icons in warning messages that support rapid legibility of the message.	
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 conspicous and legible. Minimum visual angle refers to the smallest angle at which the primary graphical elements are legible but not necessarily conspicuous [1].	

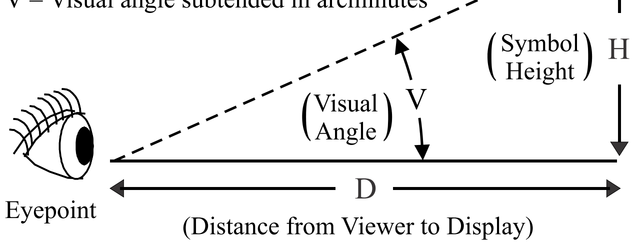
The table below provides equations for calculating the sizes of the icon, its graphical elements, text within the icon, and free-standing text. Note that the equations assume the visual angle is measured in arcminutes, symbol height is in millimeters, viewing distance is in meters, and the trigonometric 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)	—	—	$D = \frac{H}{1000 \cdot \text{Tan}\left(\frac{V}{60}\right)}$

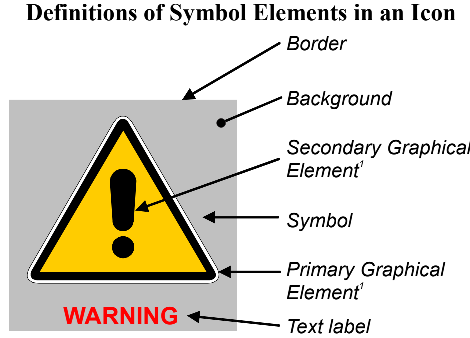
Definitions of Variables Used in the Equations

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. [2]

Definitions of Symbol Elements in an Icon



Discussion

Icon Size: The design guidance above for icon size is consistent with the recommendations made by ISO/TR7239 [1], 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 [1]—and therefore the 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 (see *Locating a Visual Display*, 6-4). ISO [3] 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 [1] are recommended for time-critical applications in order to ensure both conspicuity and legibility in the driving environment.

Text Size: ISO 15008 [4] 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 [5] 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 [6], Mourant et al. [7], Howell et al. [8], and Giddings [9] agree with the ISO [4] 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 guidance reflects the specifications for text height found in ISO [4] 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 guidance 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 [5] 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 [8, 10] (see *Characteristics of Legible Text*, 6-10).

Cross References

Locating a Visual Display, 6-4; Using Color, 6-6; Characteristics of Legible Text, 6-10

Topic References

1. International Organization for Standardization. (1984). *Development and principles for application of public information symbols.* (ISO/TR 7239). Geneva: Author.
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Characteristics of Legible Text

Introduction

Legible text is made up of several elements that support the clear presentation of information that can be easily read by the most drivers under most driving conditions. This topic summarizes information for font selection, width-to-height ratios, and strokewidth-to-height ratios that have an effect upon text legibility.

Design Goal: Use clear and simple alphanumeric characters in support of message legibility.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: **Font Characteristics and General Notes** • A clear, simple, and conventional typeface with the following characteristics is used: –Open space inside and ample space between the letter forms to prevent blurring –Highly distinguishable shapes –Proportional horizontal spacing –No extended serifs (if using a serif typeface) –No internal patterning • Abbreviations and signal words (words denoting the hazard) are presented in capital letters, or in mixed case when using fonts that maximize the text's visual angle. • Messages are presented in mixed case, except for abbreviations and signal words. **Width-to-Height Ratio** • After selecting appropriate character heights, characters have a width-to-height ratio range of 0.6 to 0.85. **Strokewidth-to-Height Ratio Notes** • A strokewidth-to-height ratio range of 0.08 to 0.2 is acceptable, with 0.167 to 0.2 preferred for critical information. • Optimum strokewidth for positive contrast (e.g., white text on a black background) is greater than that for negative contrast (e.g., black text on a white background). Note: This design guidance is closely related to the selection of appropriate character height (see page 6-8).

Comparison of text characteristics.

Characteristic	Unacceptable	Acceptable
Font	ABC Patterned	**ABC** Solid
Width-to-height Ratio	B Ratio = .4	B Ratio = .6
Strokewidth-to-height Ratio	H Ratio = .04	**H** Ratio = .167

Discussion

General Font Type and Style. Most clear, simple, and conventional fonts will be legible as long as other parameters, such as character size and contrast, are adequate [1]. Relevant standards such as ISO 15008 [2] do not prescribe a font style (such as serif or sans serif). The use of styles outside of traditional serif/sans serif (such as script and block letter) are not recommended, nor are fonts with internal patterns or extended serifs [3, 1]. A driving simulator assessment of different fonts found that visual demand level, total glance time and frequency improved with highly distinguishable shapes, varied horizontal proportions to add distinguishing characteristics, and both greater open space inside, and ample space between, the letter forms to prevent blurring [4].

Use of all capital letters for abbreviations and signal words (words denoting the hazard level, such as caution or danger) is appropriate, as common signal words are viewed and processed as icons and not text [5]. Mixed case presentation can assist with the faster word recognition, however for safety critical messages the larger visual angle of capital letters is preferable. Research examining the use of the font “Clearview” found increasing the size of lowercase letters while keeping the same overall space use of lowercase letters, can aid legibility of road signs [6]. Presentation maximizing the visual angle of signal words may reduce the need for all capital letters.

Width-to-height refers to the ratio of the width to the height of the character. There is general agreement amongst sources for these values. Most recommend a width-to-height ratio ranging from 0.6 to 0.85 [2, 3, 7], although ISO standards allow a wider range provided that other factors such as proportional spacing are optimized [2]. Note this requires basing calculations on non-single stroke characters (i.e., characters other than the numeral “1” or letter “I”).

Strokewidth-to-height refers to the ratio of the line (stroke) thickness to the height of the character; smaller strokewidth to height ratios result in skinnier appearing letters. Sources of guidance generally range from a minimum acceptable value of 0.08 to a maximum of 0.2 [2, 3, 7]. Larger strokewidths are preferred when information criticality or dynamicity increases. Greater strokewidths are required for off-axis viewing, difficult lighting conditions [7].

A specific concern is the presentation of white against a black background (negative polarity). This can lead to irradiation effects, where lighter features appear to spread into the adjacent background, especially for highly illuminated displays and/or dark adapted viewing [8]. Optimum strokewidth-to-height ratios for black characters on a white background (0.125 – 0.167) are lower than those for white characters on a black background (0.1 – 0.125).

Design Issues

It is important to select an appropriate character height (see also page 6-8). Many aspects discussed in this section follow the selection of character height. O’Day and Tijerina [9] examined multiple font characteristics and identified fonts with large character heights, wide widths, and narrow strokewidths as having acceptable reading accuracy across age groups. The reader is referred to this work for further discussion of these complex relationships.

Cross References

Selecting Character Height for Icons and Text, 6-8

Topic References

1. Wogalter, M. S., & Leonard, S. D. (1999). Attention capture and maintenance. In M. S. Wogalter, D. DeJoy, & K. R. Laughery (Eds.) *Warnings and Risk Communication* (pp. 113-138). Boca Raton, FL: CRC Press.
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Temporal Characteristics of Visual Displays

Introduction

The temporal characteristics of visual warnings involve the use of flashing, blinking and sequential illumination to simulate 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 warnings using temporal and movement features.

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

Design Guidance

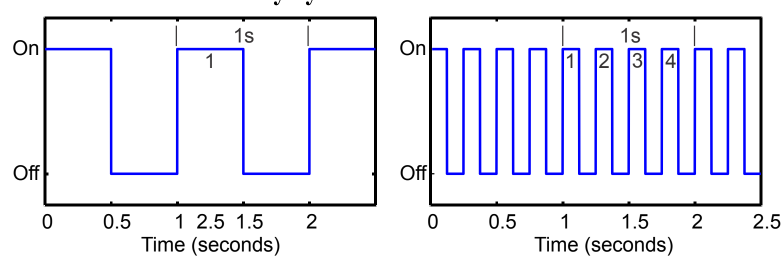
The best available research on this topic suggests that this design goal can be met when:

- A higher flash rate is used for more urgent situations—optimal rate is 3-4 Hz.
- Multiple flash mode (rapid pulses of flash for each flash cycle) is used for more urgent situations.
- Flash rate and duty cycle are adjusted as-needed to ensure driver comprehension of warning content.
- Warnings are presented in appropriate temporal proximity to the dangerous situation to elicit desired response but not a nuisance alarm.
- Flashing is used for important, suddenly-occurring situations.
- Sequential illumination is used to convey motion and/or direction, but keep text stationary.
- Other motion cues such as bouncing or zooming are not used as 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).

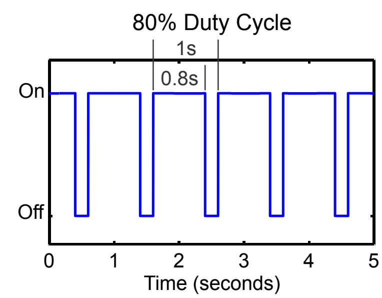
A high flash rate can be used to convey high urgency.



a) Low Frequency b) High Frequency

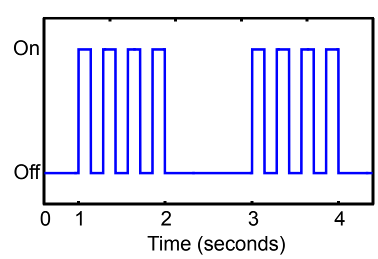
Duty Cycle: The percent of time within a cycle that the sign is in the "on" state. The example shows a signal with 80% duty cycle ("on" for 0.8s and "off" for 0.2s).

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 [1]. 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 [1, 2]. 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 [2]. 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.

The presentation of warning information in appropriate temporal proximity to the hazard is important for commanding attention, eliciting the necessary response by the driver, and to avoid nuisance alarms by warning for conditions too early. The beneficial effects of early (1.5 s prior to predicted impact) versus late (1.0 s prior to predicted impact) warnings have been demonstrated [3]. Warning timing is discussed in *Providing Forward Collision Warnings that Accommodate Driver Brake Reaction Time* (page 4-8).

Sequential illumination of display elements can be used to create apparent motion, which can convey directional information pertinent to warning systems. This can be useful for intersection management alerts, for example, in which approaching vehicles from the left or right can be signaled via sequential illumination of elements on a HUD or central instrument cluster. ISO [1] provides examples of movement in association with icons to convey dangerous situations such as emergency vehicles, icy roadways, etc. Apparent 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 et al. [4] 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 warnings, and are appropriate for use in imminent danger situations if the warning can be provided in appropriate temporal relationship to the hazard 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 Warning Messages, 4-4, Providing Forward Collision Warnings that Accommodate Driver Brake Reaction Time, 4-8; Locating a Visual Display, 6-4; Display Glare, 6-14

Topic References

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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.
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.

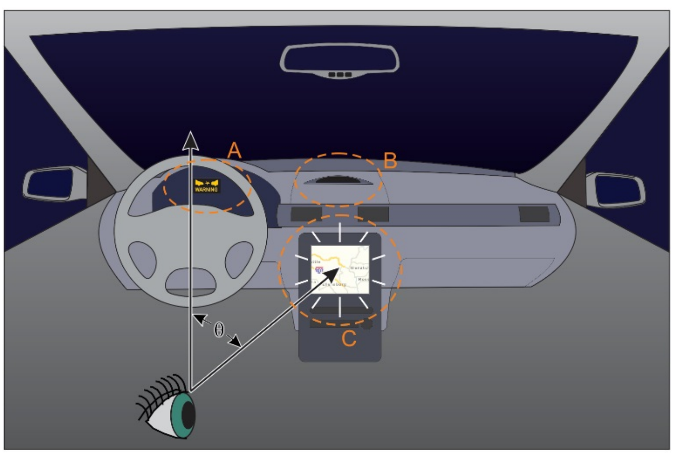
Examples of mitigations for glare incident on and emanating from the display.

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

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

$$\text{Where} \begin{cases} L_{veil} & = \text{veiling luminance } (cd/m^2) \\ E_{glare} & = \text{glare illuminance a the eye (lux)} \\ \theta & = \text{glare angle } (0.1^\circ < \theta < 30^\circ) \\ A & = \text{driver age (years)} \end{cases}$$

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

Adapted from CIE 146:2002 [1]. 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 [1, 2]. 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 [3]. 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 [1]. 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. [4] 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 et al. [5] 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, etc.) 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., 1, 3, 6]. 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 to prevent drivers from turning off the display completely [4]. 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. Relevant implications associated with location of the display are discussed in *Locating a Visual Display, pp 6-4, 5.*

Cross References

Locating a Visual Display, 6-4

Topic References

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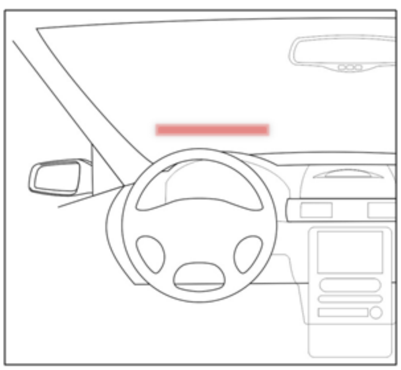
Head-up Displays

Introduction

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 [1] 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 should proceed conservatively, however, while impacts of factors such as potential distractions and driver individual differences are further evaluated. Designers should consider the necessity of the information with regard to the current driving situation when deciding what information to provide via HUD. Nevertheless, there exists a sufficient body of information on HUDs—both in aviation and, more recently, in automotive applications—to establish design guidance.

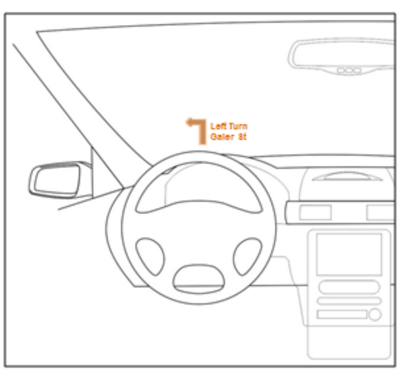
Design Goal: Use HUDs to present simple indications of critical safety situations in the driver's forward view.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • HUDs can be used to present critical forward field of view warnings that would not be appropriate for head-down displays, such as location of hazards for imminent FCWs and intersection hazards. • Information presented in the 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 presenting 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, or are redundant with road sign information is limited. • The HUD is located 5 degrees to the right and 5 degrees below the center line of driver view. • The HUD is adjustable to allow drivers with polarized sunglasses to see the information clearly.

Example of a HUD.



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

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 [2, 3]. Lind [2] 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. 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 4 Hz for 1.2s. This type of HUD is different than more conventionally designed HUDs, which may employ alphanumerics, graphics, or icons.

The balance of evidence suggests that under test conditions, HUDs or HHDDs that are located above the instrument cluster tend to improve driver performance as measured by vehicle headway distance, response time to critical events, lane keeping and other measures of driving behavior [2, 4, 5, 6]. Other work suggests that the shifting locus of attention between HUD and roadway interacts with driving workload in complex ways [7]. Liu [7] also demonstrates a learning effect, such that early use of the HUD results in inferior driving performance compared to later use within the experimental sessions.

HUD content is a complex issue—most of the experimental evaluations have addressed questions of driving performance, braking response and event detection. Some studies have evaluated multi-element displays intended for collision warning and low visibility conditions [4] while another [8] compared symbolic versus scale displays for speed control. This latter study illustrated the detrimental effect of displaying an over-speed warning on the HUD, without also including current speed—in this case, drivers had to take their eyes off the road to glance at the speedometer.

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 [9]. There is some evidence that HUDs are preferred by drivers in simulator studies, and they yield better driving performance and information detection than a head-down display [4]. Horrey et al. [5] showed that *downward* glances were increased in the post-threat period for unpredictable traffic events. This was interpreted as drivers seeking further information from the display, which was already turned off, to comprehend the nature of the just-past hazard. Thus, eyes-off-road may occur in unanticipated ways with advanced warning and control systems.

Design Issues

The specific design implementation of a HUD is a complex mix of design philosophy, attentional theory, and pragmatics, and determines the overall effectiveness of the final display. As a platform for safety messages, HUDs are most appropriate for critical forward collision and intersection warnings that are placed in or near the center of the driver's visual field. This approach reserves the HUD location for critical information that is unlikely to be extraneous or distracting. Other approaches such as vehicle speed monitoring and driver aiding systems are more complex, and involve a much larger range of display elements and properties. While there seems to be no detrimental effect of these types of displays in laboratory and limited on-road testing, 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, 6-14

Topic References

1. Prinzel, L. J., & Risser, M. (2004). *Head-up displays and attention capture* (NASA/TM-2004-213000). Available at the NASA website at http://naca.larc.nasa.gov/search.jsp?R=20040065771&qs=N%3D4294966788%2B4294724598%2B4294323833
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Chapter 7. 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 safety messages to drivers. Auditory signals can be used to convey three forms of information that are important for collision warning systems (Catchpole, KcKeown, & 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. Although all three forms of information do not necessarily need to be included in a single collision avoidance application, each of these components can provide useful information for facilitating rapid and correct responses.

Auditory signals can be effective for presenting collision warnings because they can be perceived regardless of the direction of visual attention. These signals can be very effective in warning situations when they are salient, appropriately obtrusive, and their meaning can be understood. Various characteristics of auditory warning signals can be modulated to affect the warning's 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. 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.

In general, key literature in this area suggests that the auditory modality be used primarily for imminent warnings. Because they can be perceived as annoying, and they are likely to occur frequently, auditory warnings are generally not appropriate for use in cautionary warnings. Auditory warnings, however, can be highly effective as imminent warnings, particularly as the final stage of a two-stage or graded warning system.

Topics included in this chapter:

- Auditory Display Type
- Perceived Urgency of Auditory Warnings
- Perceived Annoyance of Auditory Warnings
- Loudness of Auditory Warning Signals
- Distinctiveness of Warning Messages
- Using Localization Cues to Indicate Direction
- Presenting Warnings Using Speech Messages

Auditory Display Type

Introduction

This topic provides information for choosing the type of auditory signal (simple tone, earcon, auditory icon, or speech message) that will provide effective auditory warnings under expected conditions or that will best augment other necessary visual information.

Design Goal: Select an auditory display type that facilitates drivers' understanding of the hazard and supports appropriate and timely responses.

Design Guidance

The literature provides suggestions for selecting an auditory display type and properties to support the design goal. Table A below provides definitions and examples of the auditory signals used for warnings. Table B shows the properties of each warning type and suggests the types of applications or situations for which the sounds may be suited. However, this does not imply that a given warning type cannot be used successfully for applications other than those suggested, provided the signal includes characteristics that are consistent with the relevant driving situation.

Table A. Definitions of display types.

Display Type	Explanation	Example
Simple Tones	Single or grouped frequencies presented simultaneously.	Sine wave or square wave
Earcons	Abstract musical tones that can be used in structured combinations to create auditory messages. Sometimes referred to as complex tones.	"Ding" or two-tone chimes
Auditory Icons	Environmental sounds that intuitively convey information about the object or action they represent.	Car horn or skidding tire sounds
Speech Messages	Voice messages that add information beyond pure sound.	"Danger"

Table B. Display types, their properties, and suggested uses.

Display Type	Properties	Suggested Uses
Simple Tones	• High flexibility for conveying various levels urgency • Can be highly salient and obtrusive [1] • Can be annoying [2, 3, 4] • Meaning is not inherently known and must be learned [4]	• Highly time-critical messages, such as imminent collision warnings • Situations that require immediate action
Earcons	• Friendlier and less obtrusive sounds • Meaning is not inherently known and must be learned [2]	• Cautionary warnings* • Drawing attention to visual status information
Auditory Icons	• Can by highly salient and obtrusive [5, 6] • Meaning can be easily understood [5] • Can lead to false reactions [6] • Can be highly annoying [7]	• Imminent collision warnings • Infrequent alerts
Speech Messages	• Meaning can be easily understood [2] • Takes time to receive the complete message [1, 8] • Can be highly annoying if presented frequently [4]	• Less time-critical messages • Conveying complex information • Situations that require more detailed information

*Although auditory warnings are not generally recommended for cautionary warnings because of the potential for annoyance, under appropriate conditions (e.g., with infrequent presentation and lower-urgency characteristics), earcons could potentially be useful in this application.

Discussion

Simple tones are good for gaining the attention of the driver and, if properly implemented, can be used to warn of an imminent danger effectively. Because they are abstract, tones can be used in a variety of applications by adjusting their characteristics to convey the proper level of urgency, obtrusiveness, and salience. Simple tones have been shown to produce shorter reaction times than speech messages when used in conjunction with a visual display (e.g., Kiefer et al. [1]). However, tones can potentially be considered annoying and, therefore, might be best-suited only for conditions in which getting the drivers' attention is critical [2, 3, 4]. Other drawbacks of simple tones include the fact that their meaning is not inherently known and must be learned by the driver and that an unfamiliar tone could produce an inappropriate response [4].

Earcons often can be used to generate sounds that are friendlier and less obtrusive, which are useful properties for cautionary warnings and low-urgency applications, such as drawing attention to a visual status display. However, like simple tones, earcons are limited because their meaning is not apparent and must be learned. Consequently, they are not a good choice for presenting critical, time-dependent information to the driver [2, 4].

Auditory icons are most effective when they can be mapped to everyday, naturally-occurring sounds. These sounds may convey higher-order contextual meaning that aids in comprehension of the situation [9]. It has been shown that when appropriate auditory icons are used to announce a hazardous condition, the meaning can be recognizable by most drivers [5]. The meaning, however, must map to the driver's mental model of the situation in order for the warning to be effective. Simulator research suggests auditory icons may reduce reaction times to collision events and produce faster reaction times than simple tones or speech [5, 6]. One study [6], however, found that drivers were more likely to respond to a false alarm if it was an auditory icon versus a simple tone or speech warning. In addition, auditory icons can be highly annoying. Neurauter [7] found that the auditory icon was the least-preferred sound, and it was considered the most annoying, most interfering, and the least appropriate auditory alert compared with speech, tones, and no-auditory conditions.

Speech messages may not be well suited for time-critical warnings in situations where an immediate response is required. Most sources [1, 6, 8] agree that drivers do not respond as quickly to speech-based warnings as they do with other types of auditory displays. Moreover, because they are inherently intrusive, drivers may view speech messages as unacceptably annoying, particularly when presented frequently. Nevertheless, speech messages are an effective means of communicating information to the driver in applications that require a high degree of message detail or flexibility in terms of the message content [2] or when communicating relatively complicated information. These messages may be highly effective in the more complicated scenarios made possible by advanced vehicle technologies. For example, in a CV setting where a braking lead vehicle is occluded by an intermediate vehicle or an oncoming vehicle in the adjacent lane is occluded by a lead vehicle in a passing situation.

Cross References

Presenting Warnings Using Speech Messages, 7-14

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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: Use an auditory warning to clearly communicate a level of urgency consistent with the urgency of the hazard.

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. (Adapted from Campbell et al. [1] and Edworthy et al. [2] with additional sources as noted.)

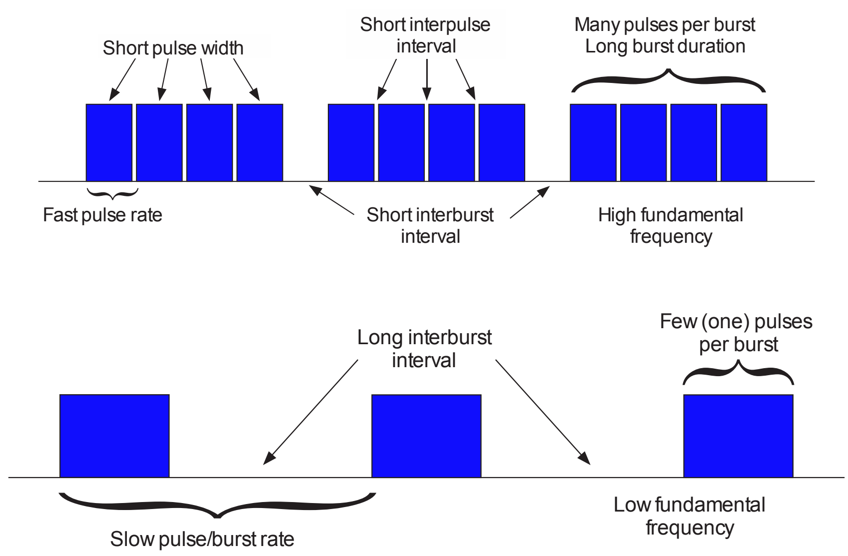
To increase the perceived urgency:

- Use faster auditory signals (e.g., 6 pulse/sec) [3, 4].
- Use regular rhythms (all pulses equally spaced).
- Use a greater number of pulse burst units (e.g., 4 units).
- Use auditory signals that speed up.
- Use high fundamental frequencies (e.g., 800 Hz) [5].
- Use random or irregular overtones [5].
- Use a large pitch range (e.g., 9 semitones).
- Use a random pitch contour.
- Use an atonal musical structure (random sequence of pulses).
- Use fast onset ramp [5].
- Use more urgent words (e.g., "Danger").

To decrease the perceived urgency:

- Use slower auditory signals (e.g., 1.5 pulse/sec) [3, 4].
- Use irregular rhythms (pulses not equally spaced).
- Use a fewer number of pulse burst units (e.g., 1 unit).
- Use auditory signals that slow down.
- Use low fundamental frequencies (e.g., 200 Hz) [5].
- Use a regular harmonic series [5].
- Use a small pitch range (3 semitones).
- Use a down or up pitch contour.
- Use a resolved musical structure (from natural scales).
- Use slow onset ramp [5].
- 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. In general, greater perceived urgency of a warning is associated with faster reaction times [1, 3]. 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 or startle responses. If auditory signals are designed with the proper level of urgency mapping 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 [1, 6-9]. Some specific characteristics that affect urgency are pulse rate, fundamental frequency, harmonic content, and (potentially) intensity. Several studies and guideline documents [1, 3, 4] suggest that increasing the pulse rate can increase perceived urgency; similarly, increasing the fundamental frequency also increases urgency. Furthermore, Edworthy et al. [2] found that signals with irregular overtones increased perceived urgency, while those with regular harmonics decreased urgency. Some studies and guidelines [6, 7, 8] 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 [10] 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 FCW. More importantly, high-intensity auditory signals can be perceived as annoying, which can negatively impact driver performance as well as acceptability [11]. When determining whether to use intensity as an urgency cue, these results should be weighed against the design guidance on pages 7-6 and 7-10 regarding the effects of intensity on compatibility, driver annoyance, and distinctiveness.

Message semantics can also influence the perceived urgency of an auditory warning. A laboratory study [5] 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 [12]. 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, 7-6; Distinctiveness of Warning Messages, 7-10; Presenting Warnings Using Speech Messages, 7-14

Topic References

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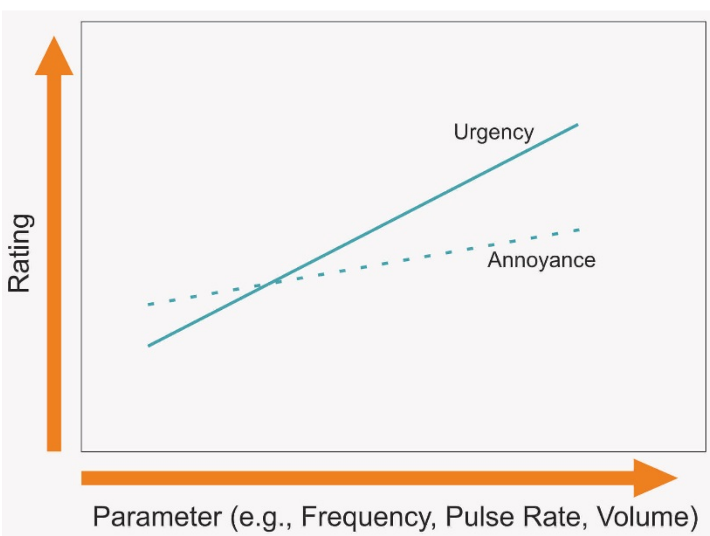
Perceived Annoyance of Auditory Warnings

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. Careful selection of warning sounds can reduce the perceived annoyance while supporting the driver's needs by presenting an appropriate level of urgency.

Design Goal: 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. • Speech-based warnings are repeated 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 intended to annoy drivers, e.g., a 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 Gonzales et al. [1].

- 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 the "annoyance tradeoff" and should be considered in signal design.

Auditory signals that are perceived to be annoying can increase workload [2], 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 fatique" when designing systems with multiple auditory warnings, even when the individual warnings are designed to minimize annoyance. Keifer et al. [3] 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 [4] 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. This finding is consistent with research [5] indicating that medical practitioners often turn off alarms that are annoying. Nevertheless, an auditory warning may be appropriate for applications that produce few false alarms if drivers perceive that its obtrusiveness and attention-getting properties outweigh the potential for annoyance [6]. See Chapter 10, *System Integration* for information that will help to minimize annoyance when implementing systems that integrate several warning applications.

Design Issues

Some sources [7, 8, 9] indicate that certain quantifiable sound parameters such as interpulse interval (time between pulses), number of repetitions, duty cycle, and frequency have a greater effect on urgency than on annoyance. Other studies [2, 1], however, found that increasing signal intensity, frequency, or duty cycle increased annoyance more than urgency. Results from Gonzalez et al. [1] suggest that if a signal parameter's psychophysical relationship with urgency is stronger than its relationship with annoyance, it is likely 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.

Cross References

Distinctiveness of Warning Messages, 7-10

Topic References

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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 should assist designers in determining appropriate volume levels for presenting clearly audible warnings to drivers.

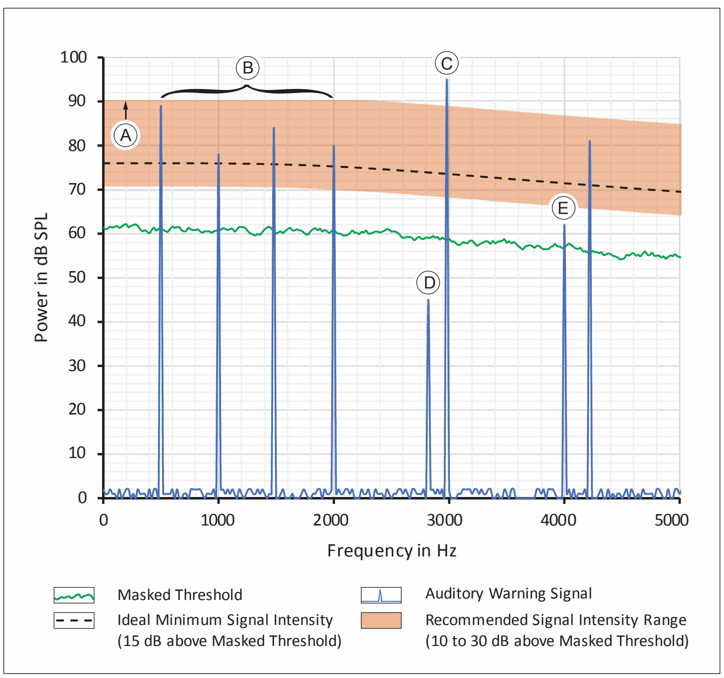
Design Goal: Select auditory warning signals that are loud enough to overcome masking sounds from road noise, the cab environment, and other equipment.

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 (e.g., [1, 2, 3]). Alternatively, the signal is at least 15 dB above the ambient noise [3].
- The signal does not exceed a maximum intensity of 90 dBA [1].
- Designers avoid presenting auditory warnings at more than 30 dBA above the MT to avoid startling or annoying drivers (e.g., [1, 2]).
- 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 [3].
- 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 [4, 5].
- 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 [6].

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

Graph adapted from Edworthy & Hellier [7]

[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

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.

Sources [1, 4] indicate that drivers can discern auditory warnings at as little as 10 dB above the MT, and recommend that auditory ICWs be 10–15 dB above the MT in order for the warning to be reliably detected. Furthermore, the standards in MIL-STD-1472G [2] 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 [3] 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. Two sources [8, 9] recommend that warning intensity be at a minimum of 20 dB and a maximum of 30 dB above the MT. In any case, the maximum amplitude of the warning should be limited.

Design Issues

Meeting these criteria can be challenging in noisy driving environments, particularly in some commercial vehicles. 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. There is some evidence that the difference between ambient noise and DVI message sounds can be smaller and still useful. In a highly controlled driving study, Lerner et al. [10] found that a higher auditory level (75 dBA) was better than a lower auditory level (65 dBA) at preserving the sense of urgency when in-vehicle ambient noise levels were moderately high (e.g., 73 to 76 dBA) and their participants actually heard the sound.

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) [6] 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 [3] 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. [4] and Campbell et al. [5] 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 *Perceived Urgency of Auditory Warnings*, page 7-4).

Cross References

Perceived Urgency of Auditory Warnings, 7-4; Presenting Warnings Using Speech Messages, 7-14

Topic References

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Distinctiveness of Warning Messages

Introduction

Auditory warning messages must be distinguishable from other auditory signals in the vehicle in order to be recognized, understood, and quickly acted upon. The general consensus among the body of research is that auditory warnings should be distinctive with respect to both non-safety messages (e.g., radio, navigation system, natural sounds, noise, etc.) and multiple safety system applications. However, some potential concerns are associated with the presence of a large number of safety applications with distinct warnings leading to the possibility that the alerts could become overwhelming or confusing to drivers. This topic discusses the rationale behind warning message distinctiveness and suggests some strategies for providing distinctive auditory messages.

Design Goal: Create auditory messages that are distinguishable from other auditory signals in the cab.

Design Guidance

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

- Auditory warnings use distinctive sounds that are easily distinguished from other sounds in the cab [1, 2].
- Vehicles that are equipped with more than one collision warning system (CWS) use auditory signals that are distinguishable between the individual CWS applications and thier associated alerts (e.g., [1, 2, 3])
- Auditory cautionary warning signals are distinctive from imminent warnings (although the auditory modality is discouraged for cautionary warnings) [3, 4].
- If simple tones are used, no more than four distinct tones are used to discriminate between warnings [3, 5].
- Too many distinctive warnings are avoided, as this may confuse drivers. Strategies such as functionally- grouped warnings may help minimize delayed reactions and driver confusion (see Design Issues).

Examples of auditory signal characteristics that can affect distinctiveness.

Type of Characteristic	Implementation
Signal Type	• Vary type (e.g., tones, earcons, and speech) between applications. • Vary characteristics within signal type.
Temporal Characteristics	• Signal pattern (burst duration, time between burst, pattern within bursts, pattern between bursts, duty cycle). • Repetition rate (fast, slow, varied).
Frequency Characteristics	• Vary fundamental frequency between applications. • Complexity (frequency and relative intensity of harmonics and/or overtones*). • Oscillations within auditory patterns.

* Harmonics are integer multiples of the fundamental frequency, while overtones can be any frequency above the fundamental.

How to make cautionary warnings distinctive from imminent warnings (Campbell et al. [6]).

For Cautionary Warnings Use:	For Imminent Warnings Use:
Lower urgency characteristics.[1]	Higher urgency characteristics.[1]
Continuous tone or intermittent with long interval.	Intermittent with short intervals.
Low signal (or pattern) repetition rate.	High signal (or pattern) repetition rate.
Low intensity.	High intensity.
Low fundamental frequency.	High fundamental frequency.
Small frequency oscillations within auditory patterns.	Large frequency oscillations within auditory patterns.
Pleasant, “friendly” sounds.	Obtrusive sounds.
Gradual onset and offset rates.	Rapid onset/offset rate (but not enough to startle).

[1]See *Perceived Urgency of Auditory Warnings* on page 7-4

Discussion

Most sources generally agree with recommendations by Lerner, Kotwal, Lyons, and Gardner-Bonneau [2] that auditory warnings should be distinctive so that drivers can quickly understand the meaning of the warning message. There are certain parameters and settings that have been shown to enhance perceptual categorization of a sound as an alert rather than a non-alert. For instance, Lerner et al. [1] found the following parameters and settings to consistently be reported as an alert rather than a non-alert: interburst interval ≥ 125 ms, base spectral frequency ≥ 1000 Hz, the number of harmonics ≥ 3 and the proportion of the pulse duration at which the signal is at full intensity ≥ 70%. Similarly, auditory signals used to alert military pilots to different conditions use specific characteristics such as intensity, pitch, harmonics, or temporal patterns [3]. In a survey of subject matter experts [7], discriminability was rated as the second most important attribute of auditory signals when designing imminent collision warnings. In a similar survey [8], both vehicle developers and truck drivers rated "easy to distinguish" and "easy to understand" as being very important.

There are limitations to the number of distinct simple tones that can be effectively recognized, with no more than five or six being absolutely recognizable [5]. Also, unless simple tones are presented in close temporal sequence, it is difficult to make qualitative judgments regarding deviations in frequency. MIL-STD-1472G [3] requires that no more than four unique tones be used if absolute discrimination is required; however, ISO [4] indicates that more sounds can be used if the tones are varied across multiple dimensions (e.g., temporal pattern, intensity, etc.) and the signal is combined with text or speech. See *Multimodal Warning Messages* on page 4-4 for more information about combining signals of different sensory modalities to enhance warning distinctiveness.

Although auditory signals are generally not recommended for presenting cautionary information, auditory caution signals should be distinct from imminent warning signals [3]. ISO/TR 16352 [4] provides guidance for providing cautionary warning sounds that are discriminable from imminent warnings. Overall, cautionary warnings should be less obtrusive and more "friendly" than imminent warnings.

Design Issues

Advanced vehicle technologies make possible the integration of many applications within a vehicle. Although, in the past, the general consensus has been that auditory warnings should be distinctive between applications. It is not clear how many distinct auditory signals drivers can learn and remember without being overwhelmed, particularly when exposure to individual messages is infrequent. Drivers must be able to recognize the alert, understand its meaning, and respond appropriately for the alert to be most effective. If there are too many distinct signals, drivers may not remember the meaning of individual signals, decreasing performance or causing driver confusion.

One way to address systems with many distinct auditory signals may be to adopt a master auditory alert strategy; however, this strategy may suffer from the challenges associated with general master alerts as discussed in *Using "Master" Warnings in Integrated Warning Systems* on page 10-4. Another strategy to consider is to make auditory signals distinctive with regard to functional groupings, such as desired response. Some support for this strategy can be found in ISO/TR 16352 [4], which indicates that auditory signals for warnings that require different responses should be distinguishable. There is little empirical data, however, demonstrating the effectiveness of distinctive sounds based on functional groupings. Finally, localization cues can be used to enhance distinctiveness, particularly when functional groupings are defined by location of hazard. See *Using Localization Cues to Indicate Direction* on page 7-12 for advantages and limitations of using localization cues.

Cross References

Using "Master" Warnings in Integrated Warning Systems, 10-4

Topic References

1. Lerner, N., Singer, J., Huey, R., Brown, T., Marshall, D., Chrysler, S., … & Chiang, D. P. (2015, November). *Driver-vehicle interfaces for advanced crash warning systems: Research on evaluation methods and warning signals.* (Report No. DOT HS 812 208). Washington, DC: National Highway Traffic Safety Administration.
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Using Localization Cues to Indicate Direction

Introduction

This topic provides guidance for designing auditory warning messages that use spatially localized cues for providing directional information. Auditory warnings that provide information about the direction or location of a hazard can help inform drivers' decision-making when responding to the auditory alert.

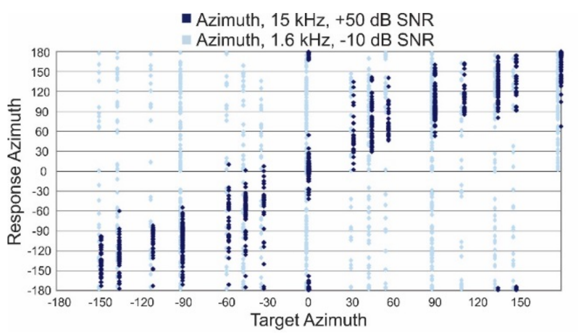
Design Goal: Create unambiguous auditory localization cues that elicit rapid and accurate responses.

Design Guidance

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

- The semantic content of directional speech alert messages is used to improve hazard detection and reduce reaction time.
- The spatial localization of an auditory alert is congruent with the semantic meaning of the message (response times are generally improved).
- Virtual speakers (sound images that are perceived to emanate from between two or more physical speakers) are not used to provide localized auditory warnings. Use discrete speakers aimed directly at the driver's head to localize sound in the direction of the crash threat.
- High-bandwidth signals with high signal to noise ratio (SNR) are localized in the horizontal plane (azimuth). Avoid signals that are localized in the median plane (elevation).

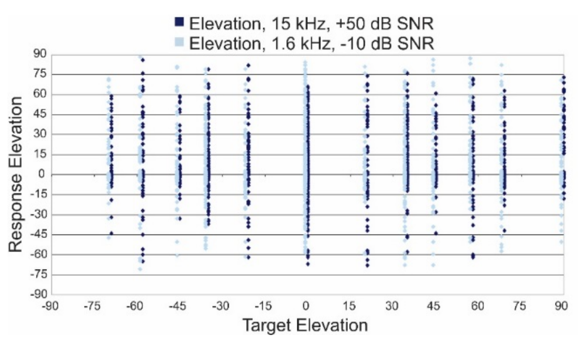
Auditory localization acuity in azimuth and elevation.



Signals localized in the horizontal plane (azimuth)

- High localization acuity associated with high-bandwidth (15 kHz), high-SNR (+50 dB) signals (dark dots).
- Poor localization acuity associated with low-bandwidth (1.6 kHz), low-SNR (−10 dB) signals (light dots)

Note the front-back confusion associated with signals localized on the median plane (i.e., at 0° azimuth).



Signals localized in the median plane (elevation)

- Poor localization acuity associated with high-bandwidth (15 kHz), high-SNR (+50 dB) signals (dark dots).
- Poor localization acuity associated with low-bandwidth (1.6 kHz), low-SNR (−10 dB) signals (light dots).

Figures adapted from Ericson et al. [1] with permission of Human Factors and Ergonomics Society, from Ericson et al. (1999). Operational constraints on the utility of virtual audio cueing. Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting; permission conveyed through Copyright Clearance Center, Inc.

Discussion

Spatially localized auditory alerts can help drivers to discern the location of a hazard. Drivers can localize a warning to a degree that is generally sufficient for providing general information about the location of a threat (e.g., forward, left-side, right-side, etc.). One study [2] found that drivers were able to identify the location of a warning emanating from a loudspeaker to within 10–20 degrees in azimuth. In systems that integrate multiple CWSs, localization may be a useful strategy for differentiating warnings generated from each system (e.g., by using an auditory signal presented in front for FCW systems, and on the side of the hazard for lane change warning [LCW] systems) [3, 4, 5].

Localization acuity and speed of response are enhanced when the auditory stimulus is congruent with the semantic meaning of the message. Several studies (e.g., Barrow & Baldwin [6], Lee [7]) found that the semantic content of directional speech alert messages improved hazard detection and localization accuracy, and reduced reaction time. Similarly, localized auditory signals can be effective when the sound is accompanied by a congruent action, such as in LCW systems in which warning information about potential conflicts becomes more important if the turn signal is activated.

Design Issues

Auditory signals can be spatially localized to draw the driver's attention in the direction of a visual display or a hazard, but with some element of risk and with some limitations. Accurate auditory localization can be difficult to achieve in the noisy and acoustically reflective environment of a vehicle cab, especially in heavy vehicles. Also, localization acuity is generally poor for sounds on the median plane (i.e., 0 and 180 degrees azimuth) [1]. In addition, sound images that are generated using virtual speakers (i.e., sounds that are localized by altering the relative timing and/or intensity of the signal between two or more loudspeakers) tend to be associated with poorer localization acuity, particularly with low-bandwidth signals under high noise conditions [1, 2]. In contrast, localization acuity is significantly enhanced with high-bandwidth signals that have a high signal-to-noise ratio. Also, localized auditory alerts may be more effective if presented from a loudspeaker at close range. Recent research [8] suggests that presentation of the signal from within the driver's peripersonal space (i.e., within arm's reach) may result in significant reductions in reaction times.

Cross References

Distinctiveness of Warning Messages, 7-10; Presenting Warnings Using Speech Messages, 7-14

Topic References

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Presenting Warnings Using Speech Messages

Introduction

This topic provides design guidance for defining the attributes of auditory signals that effectively present information through speech messages. Speech messages can convey complex concepts in unambiguous terms; however, it takes time to present the entire message. Consequently, speech messages must be used carefully in time-critical situations in order to provide information that can be quickly comprehended by the driver.

Design Goal: Select speech-based warning messages that elicit rapid and accurate responses.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • Speech is used in conjunction with a textual visual warning; the speech and visual messages need to be redundant. • Speech messages used in time-critical applications are kept to a single word or a short phrase with the fewest number of syllables possible. • Cautionary warnings are limited to three or four information units* (e.g., "Vehicle ahead—merge right"). • The gender of the voice is either male or female; however, a female voice may more readily convey urgency than a male voice. • Speech is a natural voice or synthesized. Synthesized speech must be clear and intelligible, particularly when pronounced at high word rates. • A word rate of 150 to 200 words per minute is used to convey the urgency of the warning. • Speech is not preceded with an alerting tone unless a benefit for doing so can be demonstrated. *An information unit refers to key nouns and adjectives in the message that provide unique or clarifying information. For example, the phrase "Vehicle ahead. Merge to the right." contains the four information units underlined.

Examples of speech warnings.

Warning Type	Suggested	Not Suggested
Imminent Collision Warning	"Danger"	"Vehicle stopped ahead."
Cautionary Warning	"Vehicle ahead—slow down"	"There is a slow-moving vehicle ahead. Merge to the right."

Adapted from Campbell et al. [1]

Message length for graded warnings.

Message Type	Number of Information Units	Word Rate	Pitch
Imminent Collision Warning	1 unit	200 wpm	Higher fundamental frequencies.
Cautionary Warning	2-4 units	150-200 wpm	Mid to high fundamental frequencies.
Early Cautionary Warning	2-4 units	150 wpm	Lower fundamental frequencies.

Adapted from Campbell et al. [1]

Discussion

Speech messages add information beyond pure sound and may be suitable for some warning applications. Although several sources (e.g., Campbell et al. [1], Tan & Lerner [2], General Motors Corporation [3]) suggest that speech-based warnings may not be as effective as non-speech warnings at representing high urgency or eliciting fast reaction times, speech warnings can result in faster reaction times and shorter time-to-peak deceleration times [4] when presented in the proper context. In addition, speech messages can provide important information in complex situations, particularly in scenarios that are less time-critical. Speech messages may be useful in the complex scenarios made possible by collision avoidance technologies, especially where the hazard may not be immediately apparent from the driving context alone (e.g., braking vehicle ahead occluded by an intermediate non-braking vehicle, crossing vehicle occluded by landscaping or buildings at an intersection, etc.).

Design Issues

Message length is a critical aspect of speech-based warnings—the longer the message, the more processing time that is required by the driver. Therefore, messages that require the driver to make an immediate response should be as short as possible. One-word messages informing the driver of the imminent crash threat may work best in highly urgent situations. Cautionary warnings that do not require an immediate response may use slightly longer speech messages that correspond in length to the relative urgency of the potential crash situation [1].

Speech warning presentations can be naturalistic (digitized) or machine-like (synthesized) as long as they can be perceived in the noisy environment of the vehicle, are intelligible, and can be differentiated from other speech and sounds [1, 5]. The advantage of using synthesized speech is that the qualities of synthesized speech are distinctive and attention-getting, and a machine-like voice may also better cue the driver to its identity [1]. In high-demand situations, however, natural speech may be easier for drivers to interpret and understand [6].

There is little evidence to support the choice of a male or female voice for presenting collision warnings. Tan and Lerner found that female voice messages received poorer ratings for loudness and overall effectiveness than male voices [2]. In contrast, Edworthy et al. suggest that the female voice may be preferable for presenting high-urgency messages because the higher pitch of the female voice is associated with higher urgency and the female voice was shown to be capable of producing a wider range of urgencies [7].

Other characteristics of speech warnings include word rate, pitch, and vocabulary. Faster, more accurate reactions can be realized using higher speech rates and shorter messages [5]. In addition, speech warnings should be redundant to the visual message when used in conjunction with a textual visual warning. An alerting tone should not be used to precede a voice warning unless a benefit for its use can be demonstrated; voice warnings that are preceded by an alerting tone do not produce faster response times and may increase response times compared with a voice warning by itself [1, 5].

Cross References

Auditory Display Type, 7-2; Distinctiveness of Warning Messages, 7-10

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Chapter 8. Haptic Interfaces

This chapter contains human factors design guidance for 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 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 may be included in seat belts, seats, foot pedals, and the steering wheel. 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. Some examples of this type of haptic interface are when counter-forces are applied through the accelerator pedal to "push back" the driver's foot, or when brake pulse displays cause a sudden jerky motion, or when steering wheel rotations cause the drivers hands and arms 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 are supported by concepts like "motor priming" that imply an enhanced awareness of potential responses (e.g., steering wheel rotations help drivers select steering responses). Other kinesthetic interfaces enhance awareness (e.g., vehicle brake pulses alert drivers by causing entire body motions).

Topics addressed in this chapter:

- Selecting a Haptic Display
- General Characteristics for Haptic Displays
- Improving Distinctiveness of Haptic Displays
- Accommodating for Vibrotactile Sensitivity Across the Body
- Generating a Detectable Signal in a Vibrotactile Seat
- Presenting Spatial Information Using a Vibrotactile Seat

Selecting a Haptic Display

Introduction

This topic provides information about different types of haptic displays and their uses for collision avoidance systems. Many haptic display types can serve as a display for more than one application. The additional topics in this chapter provide important information that should be used when selecting the type of display.

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

Design Guidance

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

Examples of displays that deliver haptic information.

Haptic Display	Implementation	Potential Applications
Accelerator Pedal Counterforce	Counterforce toward driver's foot that is proportional to defined error (e.g., higher force for shorter timed headway but lower force for greater headway).	• Manage following distance • Manage speed (e.g., Intelligent Speed Adaptation; ISA) • Curve Speed Warning (CSW) • Run off Road (ROR)
Accelerator Vibration	Vibration for general alerting.	• Forward Collision Warning (FCW)
Vehicle Brake Pulse	One or more short applications of the brakes to create pulses of deceleration.	• FCW • Adaptive Cruise Control (ACC) status
Steering Wheel Torque	Directional torque applied to the steering wheel.	• Lane Departure Warning (LDW) • Lateral collision avoidance • Lane Change Warning (LCW)
Steering Wheel Vibration	Vibration applied to the steering wheel.	• FCW • LDW • LCW • ROR
Vibrotactile Seat	Vibration applied to the seat or portion of the seat.	• FCW • Lateral collision avoidance • LCW • LDW
Seatbelt Vibration	Vibration motors placed within the fabric of a seatbelt.	• FCW
Seatbelt Pre-tensioner	Tightening of the seatbelt.	• FCW

Additional Notes: ISO 17361 [1] and Houser et al. [2] state that an LDW system for heavy vehicles should issue a warning via an audible or a tactile display when the warning threshold is exceeded. Visual displays are only supplemental to the main warning (as cited in Visvikis et al. [3]).

Discussion

The accelerator pedal may serve well for haptic displays that provide feedback on acceleration and speed. Applying a counterforce to the accelerator pedal has been used as feedback for driver speed [4]. Accelerator pedal counterforce may be an effective display method for a CSW as it may help drivers to significantly reduce their speed when entering a curve [4]. There has only been one study to support the use of a vibrotactile accelerator pedal as a display for a forward collision warning and the efficacy relied on the intensity of the vibration [5]. One design issue with accelerator pedal displays is the requirement that the driver's foot must be on the accelerator to receive the vibration signal. Footwear material may impede vibration to the foot, which has not been addressed in the research.

Applying a vehicle brake pulse as a haptic display has 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" [6, 7]. 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. The physical slowing of the vehicle also helps to delay drivers from entering an intersection until a hazard is no longer present [8]. 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.

There are three concepts that support using the steering wheel for a haptic display. One concept is called motor priming, which is a neuronal activity that pre-activates which limb motions to use. Steering wheel torque rotations support motor priming and help drivers select maneuvers that resolve lateral control issues [9, 10, 11]. The second concept is the idea that delivering a message through the steering wheel helps drivers to form a correspondence between the vibration signal and potential responses [12, 13]. The third concept is that the hands are highly sensitive to vibration due to physiology, which translates to a lower threshold for detecting steering wheel vibrations.

Vibrotactile seats are widely covered within the literature and will be discussed in greater detail in other topics within this chapter (see 8-10 and 8-12). Many design issues limit the use of haptic displays for delivering complex messages (e.g., directional information); 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. Also, use of a seat belt display must be done with the understanding that seat belt use is only 87 percent in the United States [14]; thus some users will not benefit from this type of display.

Design Issues

Although the seatbelt pretensioner has been marketed to drivers as a safety display there is limited available empirical evidence to support its use for a collision avoidance system display [15].

Cross References

Multimodal Warning Messages, 4-4; Selection of Sensory Modality, 5-6

Topic References

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General Characteristics for Haptic Displays

Introduction

This topic provides useful high-level descriptions of key characteristics of haptic displays. These characteristics will need careful consideration during the design of a haptic display. Many characteristics can be modified to enhance the detectability of a haptic display and to prompt drivers to respond in useful ways during crash situations.

Design Goal: Select haptic display characteristics that elicit rapid and accurate responses.

Design Guidance

The best available research suggests these characteristics may be manipulated in support of the design goal:

Key Characteristic	Description
Select either active or passive interfaces.	The selection of either an active or passive interface should correspond with the intended message: • Active Haptic Interfaces: Active haptic interfaces can be used to enhance understanding of the system message when prompting drivers for specific maneuvers. Some examples are accelerator pedal counterforce, accelerator vibration, steering wheel torque, and steering wheel vibrations [1, 2]. • Passive Haptic Interfaces: Passive haptic interfaces may require more experience or training for more complex messages as the messages less clearly correspond to the signal (e.g., spatial messages [3], or single displays that supply multiple messages that are temporally independent [4]). Note: Regardless of the message complexity, temporal aspects of passive haptic displays remain available to drivers when a message is initially delivered. Designers should avoid compromises to temporal correspondence to collision events when using passive displays that deliver complex messages to drivers.
Select activation parameters for haptic displays.	• Haptic signals need to activate with sufficient time for drivers to respond (e.g., an early FCW [5]). Generally, earlier alerts facilitate responses whereas later alerts are less useful [6] and drivers are more accepting of false alarms when there is adequate time to assess the driving scenario as trust can become impaired for alerts that are too late [7]. • Discrete events require an activation threshold (e.g., LDW lane boundary proximity threshold [8, 9]). • Monitoring events that are continuous in nature requires continuous activation (e.g., accelerator pedal force-feedback for speed maintenance [2], feedback on car following headway [10] or even blind spot monitoring [11]).
Support haptic display redundancy.	• 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 [4] and steering wheel [13].

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

Rule of thumb: 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 and steering wheel rotations more frequently result in faster reaction times or better selection of appropriate driving maneuvers [1].

Discussion

Auditory and visual displays can use language to directly specify the meaning of a message, or they can deliver a message indirectly through the use of icons and auditory tones. 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 a 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 [5, 6]. Adequate timing (e.g., 0.7s for severe braking [5]) may help considerably when drivers need to derive a message from an indirect signal. One initial step for designers is to determine whether an Active or Passive interface supports the design parameters of their application. *Active haptic interfaces* use active purposeful touch and typically send haptic signals through control devices to enhance responses; some examples are haptic steering wheel displays that activate when steering responses are most appropriate [1], and haptic accelerator pedal displays that activate when changes to acceleration or speed are desired [2]. *Passive haptic interfaces* use passive receptive touch and typically send signals to body areas that are not used to carry out the motor control required of the corrective response. Some examples are vibrotactile seat displays for delivering messages about hazard locations, lane departures, intersection violations, curve speed, etc. [3, 4]. Active displays are commonly paired with certain applications (e.g., lane change decision assist systems [LCDASs] and ISA systems) and passive displays have been broadly applied, e.g., FCW, LCDASs, navigation, spatial information, intersection movement assist [IMA], etc.).

Information about discrete events can be supported using active or passive displays. For example, passive displays can support discrete events like lane departures. When haptic signals are in temporal correspondence with a lane departure, general vibrations from the driving wheel [1] or the seat [8] can be quite effective. Note that nuisance and false alarms are inherently associated with discrete or binary warnings for continuously changing control tasks like monitoring headway during car-following [10]. As a solution for a similar driving task, vibrotactile seat was recently used as continuous blind-spot monitoring display [11] and although effective, significant research is still needed despite the notion that continuous haptic feedback can at any time temporarily replace visual feedback [9].

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 [13], 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 [4, 14], and experience [3].

Cross References

Designing Messages for Driver Comprehension, 5-2; Selection of Sensory Modality, 5-6

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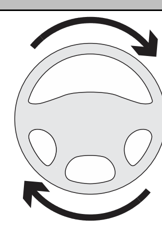
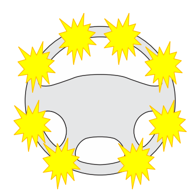
Improving Distinctiveness of Haptic Displays

Introduction

This topic contains information on how to make haptic displays perceptively distinct. The design goal below originates from ISO 17387 [1] 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: Ensure haptic warnings are clearly distinguishable from other haptic signals in the vehicle.
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 [2]. Note, the duration of high intensity signals can affect driver comfort levels. • There is a limit to the number of locations for simultaneous vibration signals. Do not deliver multiple simultaneous vibrations across the body [3]. • Designers create apparent motion within vibrational surfaces 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 tactor motors needs to exceed the two-point threshold discussed on page 8-8. • Sufficient training or documentation is provided for uses of multiple vibrotactile haptic signals that represent different messages in a single system.

Example of how to differentiate the warning cues from environmental vibrations.

More Difficult to Detect	Easier to Detect
Low frequency, low-torque, rotational oscillations of the steering wheel may be too similar to natural variation in steering wheel position while driving. 	High frequency vibrations from tactors embedded in the steering wheel may be more differentiable from natural vibrations at the steering wheel [e.g., 5, 6]. 

Examples of perceptibly different vibrotactile signals in the driver seat [7].

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

Note: 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 [1]. The design methods mentioned in this topic are not mentioned within the standard.

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. Ryu et al. [2] accomplished this by mounting accelerometers to multiple locations within their test vehicle (e.g., the center fascia, gear lever, and steering wheel) then they measured vibration frequency and amplitude while driving the vehicle under various conditions (e.g., driving at 60 km/h on a city road and 100 km/h on a highway). The spectral output of their measurements, which had a principal frequency of 60 Hz, was used to determine the vibrational intensity of their haptic display. Their goal was to reduce the masking effect that natural vibrations cause, and they accomplished this by selecting frequencies that exceeded the measured natural ambient vibration (e.g., 80, 140, and 250 Hz). 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 [8].

Results from Tijerina et al. [4] show that low intensity steering wheel torques did not result in enhanced driver performance, but this may have been a result of the steering wheel torque lacking correspondence with the required driver response (in this study, braking) instead of a fundamental issue with the display presentation (see also other topics addressing stimulus-response compatibility such as *Visual Display Type for Safety-related Messages*, page 6-2). For steering wheel haptic displays with higher correspondence with the hazard response (e.g., a LDW steering wheel display), torque applications may improve responses [9]; alternatively, tactor motors could be used to generate moderate to high vibrations [5, 6] that do not occur naturally.

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 [2], but without this instruction drivers may still benefit from general alerting properties [7].

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 [10].

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. The reason to avoid sending simultaneous haptic signals to the driver is that humans can only pay attention to a small number of vibrations occurring simultaneously across the entire body [3]. 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, 5-2; Visual Display Type for Safety-related Messages, 6-2

Topic References

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Accommodating for Vibrotactile Sensitivity Across the Body

Introduction

This topic describes how a vibrotactile display should correspond 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: Select a vibration intensity consistent with the sensitivity of the targeted body location.

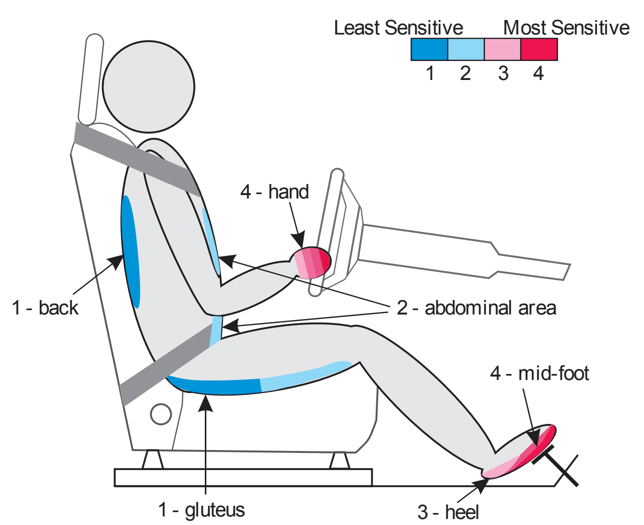
Design Guidance

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 [1], and generally high between 150 and 300 Hz [2].
- Vibration intensity is increased or decreased by adjusting vibration frequency or amplitude, but not both. Note that only relative vibration settings are possible for some vibrotactile displays that consist of certain types of tactor motors (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 [3]).

Examples of locations for varying vibrotactile intensity.

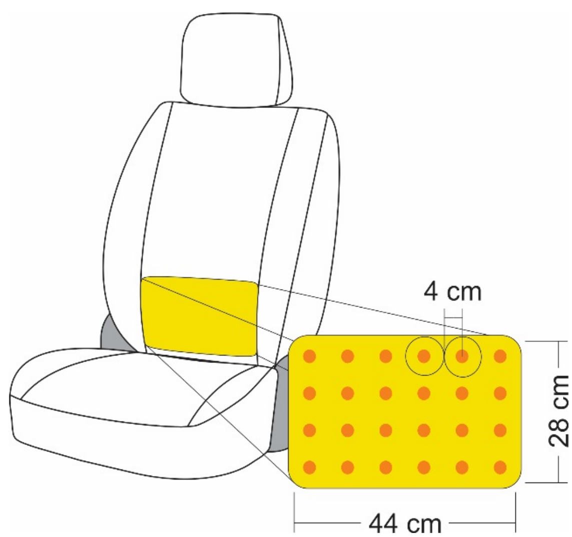
Vibration sensitivity across body locations



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 effect how well vibrations are perceived.

Minimum density of vibrating motors



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

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

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

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 [1, 2, 4, 5].

Basic research has shown that increasing the vibrational surface area of a vibrotactile display increases perceived intensity [2, 6]. 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 one potential individual difference across people for their sensitivity to vibration [2]. Amplitude and frequency of vibration can be used differentially within certain vibrotactile displays (e.g., Rosario et al. [7]) but not all (e.g., Ji et al. [86]). When testing vibration parameters, it will be important to note the vibrational elements that accomplish end-user performance goals.

Reiner [3] 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, etc.).

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 [4]**.** 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 for a lane departure warning (e.g., Suzuki & Jansson [5]) tend to enhance response time as a result of better correspondence between the warning and the required maneuver. Although hands have greater discriminatory power than other body regions, hands are often used for other tasks [4]. This may be an issue when integrating haptic displays with other systems that require the driver to interact via the hands (e.g., vibrotactile steering displays).

In addition, the correlated effect of frequency and amplitude in perceiving vibration is different across the body. Displacement also has a stronger influence at some locations (e.g., the abdomen) and frequency has a stronger influence at other locations (e.g., the fingertips) [2]. This will become a design consideration when determining whether or not to increase intensity by changing vibration frequency or amplitude. To support display redundancy, use large vibrating surfaces to ensure the haptic display makes contact with the driver; this can be accomplished using multiple vibrating motors embedded in the seat [9].

Cross References

Selection of Sensory Modality, 5-6

Topic References

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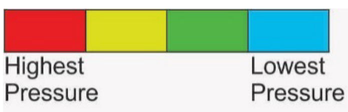
Generating a Detectable Signal in a Vibrotactile Seat

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.

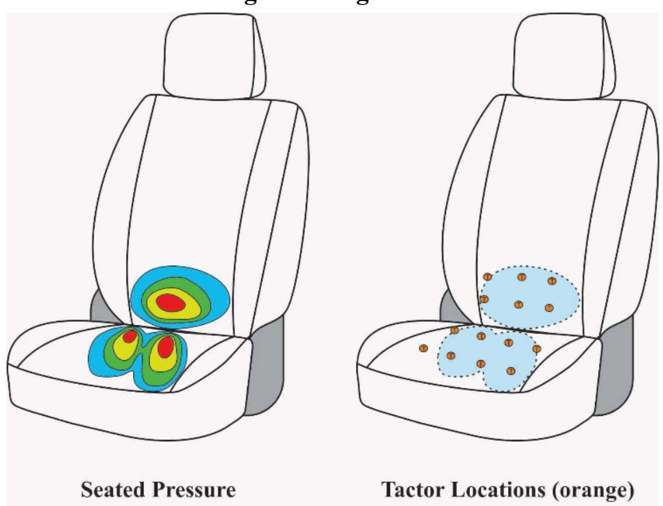
Design Goal: Ensure drivers can feel the vibrations from the vibrotactile seat.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • There is contact between the driver and the tactile display. To do this, place tactors where seated pressures are 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.



Example of a detectable vibration measurements from seat pan and and back rest surfaces of a *vibrotactile seat display* [2]:

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 [2, 3, 4, 5]. Three potential reasons for designers and researchers to do this are:

1) Seat-pressure distribution information provides an indication of where on the seat the driver is actually or most likely to be seated [5],
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 [6], 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 the 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 [2, 4, 7], 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 [6].

Although only a few relevant studies demonstrate that both vibration frequency and amplitude are important for making an effective vibrotactile display [1, 2], this concept is well supported and universally accepted.

There are many potential 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 [2]. 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; some vibrotactile displays rely upon rotation of an eccentric mass 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 that 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 that the tactors that are located at the highest seated pressure zone are active and the signal is appropriately intense [5].

The physical distance between the driver and the vibrating motor plays a role in how much of the signal actually reaches the driver [6]. The greater the distance between the driver and the vibrating motor, then less of the actual signal reaches the driver.

Cross References
Accommodating for Vibrotactile Sensitivity Across the Body, 8-8

Topic References

1. Rosario, H., Louredo, M., Diaz, I., Soler, A., Gil, J. J., Solaz, J. S., & Jordi, J. (2010). Efficacy and feeling of a vibrotactile frontal collision warning implemented in a haptic pedal. *Transportation Research Part F: Traffic Psychology and Behaviour*, *13*(2), 80-91.
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Presenting Spatial Information Using a Vibrotactile Seat

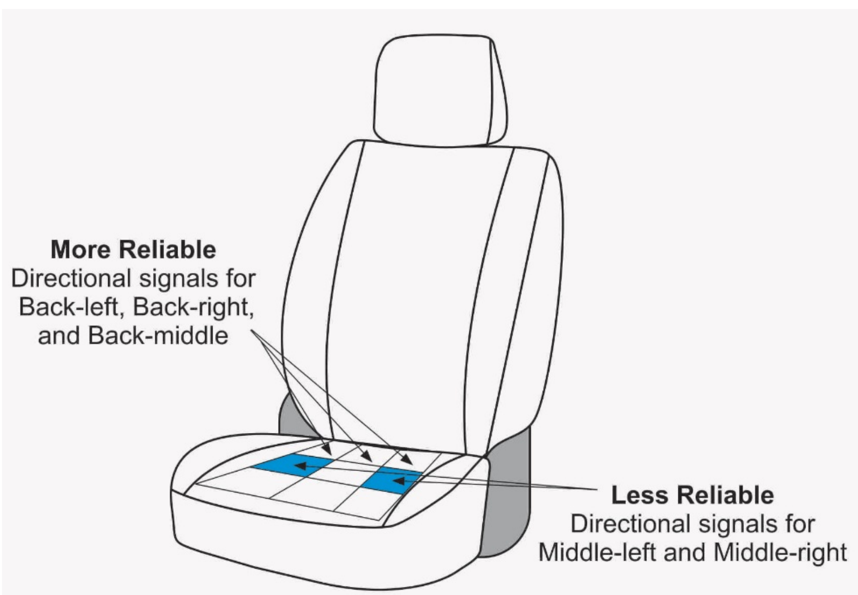
Introduction

Properly designed vibrotactile seat displays can provide drivers with non-visual information regarding directional elements of a situation. This topic contains information on how to implement a spatialized vibrotactile driver seat. Also highlighted are caveats regarding driver perception of directional information from a vibrotactile seat.

Design Goal: Use a vibrotactile seat to present spatial information that is localizable and spatially informative.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • There is sufficient separation between vibrational surfaces within the seat for drivers to perceive distinctively different vibrating locations. The following considerations are pertinent for localizable arrangements: – A separation distance that corresponds to 75 percent or more of users agreeing there are two signals that are spatially separated [1] is used. Without sufficient separation drivers may report sensing a single vibration rather than spatially independent vibrations, which will lead to difficulty deciphering the implied spatial information. – A threshold of 75 percent accuracy is used to test the comprehensibility of directional signals: 75 percent of all tested driver responses should be correct regarding the implied spatial message (e.g., left, forward, etc.). – The vibration surface area is of sufficient size to accommodate for variations in driver sensitivity [2, 3]. • Spatial information is presented in advance of the relevant event. Drivers need adequate time to decipher the direction implied by the vibrotactile signal. Precise spatial correspondence cannot be attained due to the Correspondence Problem [4] (see also Design Issues).

Example of vibrotactile seat with 4 cardinal planes and oblique directions [2, 3].

A seat consisting of a 9 x 9 tactor array is shown below. Directional signals for the back-left (BL) and back-right (BR), and back-middle (BM) were reliably detected but accuracy may be slightly poorer for middle right (MR) and middle left (ML) directions (less than 75% accuracy in Fitch et al. [2] only).



Discussion

Although the research examining effectiveness of delivering spatial/directional information to a driver through a vibrotactile seat is quite limited, there is sufficient information within the literature to provide information on design elements.

When testing vibrotactile seat display design options using seated drivers, in order to deliver a spatialized message there should be enough space between each vibrating region within the seat to cause the driver to sense that there are multiple locations within the seat that vibrate. Appropriate spacing accounts for the low spatial resolution of mechanoreceptors in the back [5, 6], gluteus and thighs [7]. If the space between vibrating areas is not sufficient, drivers may not be able to localize the vibrations, which will render the information spatially uninformative. Note if the directional cues are not percieved, any temporal cue associated with the activation of the vibrating surface may provide a generalized alert.

The size of the vibrating surface used to present spatialized messages also needs to correspond with the sensitivity of the areas of the body that are in contact with the display. A few researchers have generated large vibrating surfaces by simultaneously activating a set of adjacent tactors located within a larger array of tactors [2, 3]. There are two justifications for using a larger surface area: (1) it accommodates for the wide range of individual differences in vibration sensitivity across drivers; and (2) it accommodates real-time changes in driver posture by incorporating redundancy into the signal—redundancy results from the larger size of the total vibrating surface area increasing the likelihood that a portion of the driver's body remains in contact with the vibrating region.

The 75 percent criterion for determining the minimum separation distance for drivers to detect two vibrations is based on the Difference Threshold, which can be obtained using the classical technique called Method of Constant Stimuli [8] where multiple separation distances are presented to test subjects. This method requires a full range of test distances between detecting a single vibration (e.g., 10 mm spacing) and detecting two separate vibrations (e.g., 80 mm spacing). Then, starting at either end of the range, the separation distance should be lengthened or shortened and presented multiple times until a distance is found that corresponds to the threshold criterion. The same accuracy threshold value is also recommended to determine the understandability of the spatial direction.

Design Issues

*The Correspondence Problem—Tactile Cuing of Visual-spatial Attention is not Automati*c: When the correspondence between the vibrational signal and what it represents is not natural it must be formed by the driver [4, 9]. Fortunately, because vibrotactile signals do not automatically capture visual-spatial attention, the potential general alerting effect produced by any type of vibrotactile signal remains available to the driver whether the signal is intended to be spatialized or not. In general, people are able to ignore non-informative spatial vibrotactile signals during visual search and can still respond with promptness similar to no signal [10]. Experience and training may help to make the spatial/directional information from vibrotactile seats become more useful.

Cross References

Accommodating for Vibrotactile Sensitivity Across the Body, 8-8; Generating a Detectable Signal in a Vibrotactile Seat, 8-10

Topic References

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Chapter 9. Driver Inputs

This chapter provides information related to driver inputs for crash warning systems (CWSs). Most of the topics included in this chapter are created from basic human factors information, previously published guidelines, and current standards. In general, the current research related to CWSs more often focuses on the warnings displayed rather than the driver input controls; however, controls can be provided for system functions such as power (on/off), adjusting the intensity of the auditory output, adjusting the luminance of the visual display, system sensitivity (e.g., warning threshold, range), and other applications. Additionally, along with classic physical controls, touchscreen and voice controls have become more prevalent, particularly in multi-function displays.

At a high level, well-designed controls may reduce the frequency and complexity of driver interactions while the vehicle is moving. This may minimize driver distraction and eyes-off-road time, which is particularly important since the driving task requires high levels of visual attention. Well-designed controls can allow drivers to quickly and easily find the control, discern how it is used, and perform the operation with minimal error. A timely and intuitive system response following the driver input may also support driver performance.

It is difficult to definitively guide the design of controls for a CWS due to the multitude of ways that the systems could be implemented. The system may be a component of the originally installed equipment, it could be an aftermarket addition to the vehicle, or it could be incorporated into a nomadic device. Each of these system implementations has its own specific constraints that it imposes on the interface controls.

Topics addressed in this chapter:

- General Guidance for Driver-DVI Interactions
- Control Placement
- Selecting Physical Control Type
- Control-movement Compatibility
- Control Coding
- Labels for Controls
- Voice Recognition Inputs

General Guidance for Driver-DVI Interactions

Introduction

This topic provides specific information about the design of CWS controls to benefit driver safety and usability. The purpose and operation of controls should be obvious to drivers [1]. CWS controls that are easy to understand and operate minimize the level of distraction from the driving task. Poorly-designed CWS controls may adversely affect or impair the operation of primary driving controls. Therefore, designers should carefully consider the placement and operation of CWS controls in relation to other controls and displays [2, 3]. Since this is a broad topic and little research has been completed specifically on control design for CWSs, the design guidance below is primarily supported by basic human factors information.

Design Goal: Provide controls allowing for operation with minimal mental effort, eye glances, and hand/finger movement.
Design Guidance
The best available research on this topic suggests that this design goal can be met when the controls: • Have both timely and clear visual, tactile, or auditory feedback for control activation [4, 5]. • Have identifiable labels (symbols or text) that are visible and located close to the control [5]. • Are easily understood and interpretable [5]. • Are placed so they do not adversely affect or interfere with other critical system components or primary driving controls. • Are sized to provide a sufficient grasp area and space for hand/finger clearance [5]. • Are paced so they do not require an uninterruptible series of visual-manual interactions [4]. • Do not compromise the driver's choice to keep at least one hand on the steering wheel at all times. AutoAlliance [4] 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 [4].

Methods of control evaluation [5].

1. Reference and apply available methods, tools, models, customer feedback databases, and 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 [4]. Feedback could include a response to control activation, such as physical and auditory click of a button press, or a response from a system display, such as an informational dialog box. 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 turn their attention back to the roadway, without making second inputs or having uncertainty about the system status.

Identifiable: Controls are often labeled with the control function, its settings, or both. SAE Recommended Practice J1138 [6] provides information on when control functions or settings should be labeled (also see Labels for Controls, 9-12).

Interpretable: CWS controls should be intuitive to operate. The control design and movement should match the driver's expectations of how the system and application function (see Control-movement Compatibility, 9-8).

Placement: CWS controls should be placed such that the operation of the control does not adversely affect the operation of a primary driving control. More information can be found in Control Placement, 9-4.

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.

Pacing: Auto Alliance [4] provides a range of guidance regarding the pacing of control interactions. 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. CWS interactions should be designed to require that only one hand at a time needs to be removed from the steering wheel [3]. Auto Alliance principles state that interactions with steering wheel-located controls should not require simultaneous inputs from both hands unless one of the hands only requires a single finger input [4].

Design Issues

Complex interactions, such as initial control settings, should be reserved for times when the vehicle is stopped [7]. 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 [2, 8]. The system should clearly indicate those functions that are not for use while driving and when they are inaccessible [4].

Topic References

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Control Placement

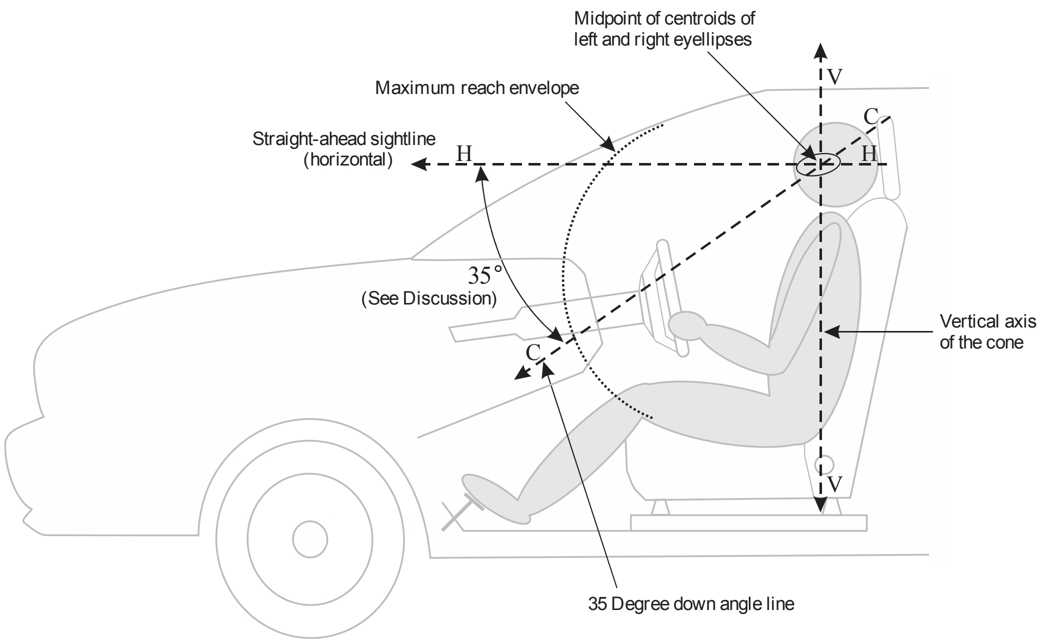
Introduction

This topic provides information about the placement of CWS controls in the vehicle. The application and placement of these controls must not interfere with the primary task of driving the vehicle. Drivers should be able to find, reach, and comfortably use controls in the location that they are placed. Little specific research on the placement of CWS controls has been conducted; therefore, this topic primarily reflects more general in-vehicle control placement information and design convention.

Design Goal: Ensure control placement and operation does not interfere with the driving task or the use of other driving controls.
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 [1]. • Are located in a visible area or can be found blindly [1]. • Do not obstruct the driver's field-of-view, vehicle displays, or other vehicle controls [2]. • Are placed such that they are not obstructed by other vehicle controls or displays [1]. • Do not require the driver to reach their whole hand through the steering wheel [2].

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

Diagram of ideal control placement region relative to the driver [1].



Adapted from Bhise [1] with permission of CRC Press, from Bhise, V. D. (2011). Ergonomics in the automotive design process; permission conveyed through Copyright Clearance Center, Inc.

Discussion
Controls that are within a driver's maximal reach envelope are shown in the figure on the previous page. 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 [3]. 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 [1]. Stevens et al. [4] and ISO [5] 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.

CWS controls should not obstruct or interfere with the use of other controls or displays. Stevens et al. [4] 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.

In field operational tests of forward collision warning (FCW) and adaptive cruise control (ACC) systems, controls for setting the cautionary warning sensitivity level and the ACC headway gap were placed in the steering wheel, with the higher priority CWS controls positioned near the outer edge of the steering wheel where they were easier to manipulate [6]. 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 CWS control, which could result in the CWS operating differently than how the driver expects.

Design Issues
Nomadic devices (e.g., smartphones, navigation devices) have the future potential to provide collision warnings using the device interface. These devices provide unique challenges from both a warning perspective and a driver input perspective because the driver can position them anywhere within the vehicle. An option for informing drivers of appropriate locations for device placement is to use device-embedded instructions or training material to provide that information.

Topic References

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Selecting Physical Control Type

Introduction

This topic provides recommended control types (i.e., discrete, continuous) and example controls for four functions that are recommended to be adjustable [1]. The majority of recent studies and discussion about CWS controls have focused on what controls to provide; there is little data available regarding which control type should be used to implement a given CWS function. Recommendations for discrete versus continuous controls reflect more traditional human factors design principles and are based on the type of adjustment required for a particular function. Some CWS controls (e.g., on/off) require discrete controls (controls that provide distinctive, individual values), while others are more suited for implementation with continuous controls (controls that provide a continuous range of values). Yet other CWS controls may be implemented using either class of control (e.g., warning timing [2]). In this case, the designer must determine which class of control will most benefit the driver while best fitting the application and the control function.

Design Goal: Match a CWS physical control's form and function to the requirements of the CWS.

Design Guidance

The second and third columns in the table below identify control types that the research suggests may be used for each CWS function. These control types correspond to the candidate controls found below the table. A dash in the second or third column of the table indicates that no data were found to either support or reject the use of this control type for the corresponding CWS function.

CWS Function	Use Discrete Control?	Use Continuous Control?
On/Off: Enables and disables the CWS.	Yes 2-position	No
Auditory Intensity: Controls the intensity of the auditory warning display.	—	Yes Gross Adjustment
Visual Display Luminance: Controls the intensity of the visual warning display.	—	Yes Gross Adjustment
Sensitivity (Warning Timing, Warning Threshold, Range, Time-to-Collision; TTC): Controls the physical or temporal proximity threshold for which warnings are activated. This might also apply to ACC gap/headway controls.	Yes Multi-Position	Yes Precise Adjustment

Candidate controls for CWSs.

Candidate Discrete Controls		Candidate Continuous Controls	
Multi-Position	**2-Position**	**Gross Adjustment**	**Precise Adjustment**
• Slide • Multipurpose stalk • Discrete rotary knob • Three-position toggle switch • Three-position rocker switch • Push-buttons (for three alternatives only) • Key pad	• Toggle switch • Two-position stalk • Push-pull knob • Push-button • Rocker switch	• Continuous rotary knob • Lever	• Continuous rotary knob • Thumbwheel

Discussion
There are differences in opinion regarding whether adjustments for specific CWS functions should be provided. Although Lerner, Kotwal, Lyons, and Gardner-Bonneau [1] recommends that all of the functions described on the previous page be adjustable, current standards generally leave the decision up to the system designer. The following paragraphs provide some discussion of the pros and cons of providing those adjustments, as provided by current research and standards.

On/Off: Lerner, Kotwal, Lyons, and Gardner-Bonneau [1] recommends that the driver should be able to manually disable the CWS to avoid the occurrence of false or nuisance alarms. Pomerleau et al. [3] also recommend that the driver should have the ability to disable the CWS in situations that cause false alarms to frequently occur (e.g., in work zones). A similar situation might occur when a driver uses a turn signal to indicate a desire to change lanes when the target lane is completely occupied. Wilson et al. [4], however, take the opposite view, that under no circumstances should the driver have the ability to disengage the CWS, thus ensuring that the warning is available in the event of a true collision situation.

Auditory Intensity and Visual Display Luminance: Almost all sources recommend that controls be provided for adjusting both auditory warning intensity and visual display luminance. One source recommends, however, that alarms should not be adjustable or defeatable [5]. In addition, the source recommends that other auditory systems (e.g., radio, navigation system) should not be capable of producing uncontrollable volume levels that mask interior or exterior alarms [5]. SAE J2400 [6] cautions that if the visual display is a tell-tale (i.e. an icon or a symbol that indicates or warns of a problem or issue that has occured), the visual luminance should not be adjustable.

It is important to consider appropriate limits for the adjustability of the functions described in this topic. For the on/off function in CWSs, it is commonly specified that the activation state should be communicated to the driver (e.g., SAE J2808 [7]). Accordingly, when the driver believes the system is active, they would expect to experience warnings in applicable situations. This necessitates limits to the adjustment of auditory intensity and visual display luminance so that drivers cannot adjust them to the point of imperceptibility. Auditory warnings need to be heard over ambient vehicle noise, yet not startle the driver [6]. Additionally, visual displays should be visible at the dimmest setting [6], yet dimmable to mitigate glare [7]. See *Loudness of Auditory Warning Signals* on page 7-18, and *Display Glare* on page 6-14 for information on auditory intensity and visual display luminance limits.

Sensitivity: Headway/TTC and sensitivity controls generally determine some threshold at which the warning display is activated. In order to accommodate personal driving styles and prevailing driving conditions, drivers may prefer to adjust the headway/TTC settings. Likewise, drivers might adjust the sensitivity to reduce the occurrence of false and nuisance alarms. The risk involved in providing these adjustments is that drivers may inappropriately adjust the controls to settings that reduce or eliminate the effectiveness of the CWS (i.e., alerts are presented too late to effectively warn the driver of an imminent collision [8]). Nonetheless, these adjustments have been successfully implemented in empirical studies. General Motors [9] found that drivers used the full range of these adjustments and tended to adjust the sensitivity to settings that produced fairly early presentation of cautionary warnings, even though the "later" setting would completely suppress the cautionary warnings. In another study [10], three transit bus operators used the full range of settings; one driver predominantly used the minimum sensitivity setting in order to minimize false alarms, while the others predominantly used the middle setting in order to balance the frequency of false alarms with the amount of time provided in the warning.

Cross References
Control-movement Compatibility, 9-8

Topic References

1. Lerner, N. D., Kotwal, B. M., Lyons, R. D., & Gardner-Bonneau, D. J. (1996, January). *Preliminary human factors guidelines for crash avoidance warning devices* (Report No. DOT HS 808 342). Washington, DC: National Highway Traffic Safety Administration. Available at https://archive.org/download/preliminaryhuman00lern/preliminaryhuman00lern.pdf
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Control-movement Compatibility

Introduction

This topic provides guidance for achieving control-movement compatibility, which is the expected relationship between control activation movements, the corresponding changes in the system being controlled, and any associated display outputs.

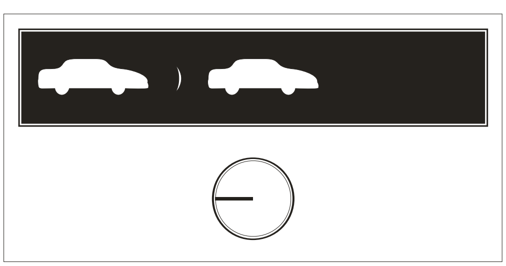
Design Goal: Ensure control movements cause a predictable change in system status, whether it be for a discrete function (e.g., on/off) or a continuous function (e.g., volume).
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • Control movements correspond to the expectations of the user. See the table below for recommended control-movement to system-function relationships. • There is a strong correspondence between the control-movement to system-function; this is important when there are multiple options for a control movement (e.g., expectations for "up" to increase are probably stronger than those for "clockwise" to increase). Note that it is important that the choice of control-movement to system-function relationship does not adversely affect the driver's ability to use the system.

Recommended control-movement to system-function relationships [1].

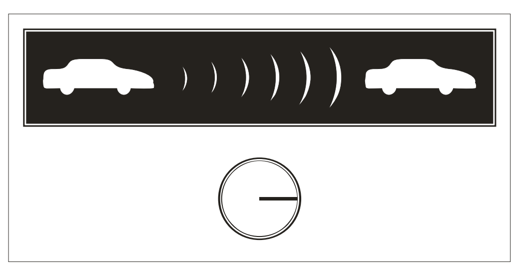
System Function	Control Movement
On	Up, right, forward, pull
Off	Down, left, rearward, push
Right	Right, clockwise
Left	Left, counterclockwise
Up	Up, rearward
Down	Down, forward
Increase	Up, right, forward, clockwise
Decrease	Down, left, rearward, counterclockwise

Example of sensitivity control-movement compatibility (clockwise to increase).

In this example, the display indicates that the system sensitivity setting is increased with a clockwise rotation of the rotary control. The relationship between the control movement and the display provides additional meaning that describes the effect of adjusting the control.



Minimum Sensitivity



Maximum Sensitivity

Vehicle proximity graphic from General Motors Corporation [2]

Discussion

Effective controls employ movements that are consistent with drivers' expectations or control stereotypes. Making the activation of the control consistent with familiar driver movements will result in decreased reaction times, learning times, and control errors. Control-movement compatibility also will reduce a driver's cognitive demands and increase driver satisfaction [1, 3]. In contrast, controls that do not produce expected system behavior can result in annoyance, distraction, increased reaction/operation time, errors, and dissatisfaction. The table on the previous page describes control-movement to system-function relationships that are consistent with driver expectations [1, 3].

Control movements that are standardized help to avoid driver confusion when operating vehicles equipped with systems from different manufacturers. Existing standardization also can be exploited for control concepts that are similar to existing controls with which drivers are already familiar. For example, many drivers are familiar with conventional cruise control. An adaptive cruise control system with FCW should extend the familiar controls of conventional cruise control to provide the added CWS functionality [4].

Design Issues

When the movements of some controls involve multiple conflicting compatibility relationships, it may be necessary to violate one relationship in order to take advantage of another. An example is a rotary stalk control that increases some parameter of a function by rotating the right-hand stalk in the counterclockwise direction or up. The upward movement is appropriate for increasing the parameter, but the counterclockwise movement is not. To provide the most effective control, the designer must determine which movement complies most strongly with the driver's expectations or which relationship can be violated without adversely affecting the driver's ability to use the system.

Three general principles apply when designing controls with associated linear displays (e.g., a gap indicator, FCW warning timing threshold). Strong stereotypes result when all three principles are combined. These principles are listed as follows [5]:

- Clockwise activation produces an increase in displayed value.
- Subjects expect the indicator to move in the same direction as the part of the control nearest the display.
- Subjects expect the indicator to move in the same direction as the side of the control knob that is adjacent to the scale markings.
-

Cross References

Labels for Controls, 9-10

Topic References

1. Campbell, J. L., Carney, C., & Kantowitz, B. H. (1998). *Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO)*, (Report No. FHWA-RD-98-057). Washington, DC: Federal Highway Administration.
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Control Coding

Introduction

Control coding is the set of design characteristics that serve to identify the control or to identify the relationship between the control and the function to be controlled. This topic discusses the advantages and disadvantages of different types of control coding.

Design Goal: Choose control coding that supports quick and accurate identification by drivers, reducing eyes-off-road time.

Design Guidance

The best available research suggests using one or more of the following characteristics to identify controls:

- **Location Coding:** In order to ensure discriminable and unique control locations, controls may be separated by distances that are sufficient to avoid confusion among positions.
- **Shape Coding:** This is most effective when used in combination with location coding. Errors in the driver's hand position are indicated by the feel of the control.
- **Size Coding:** This is most effective when used in combination with location coding. As many as two or three sizes can be used to discriminate controls.

Advantages and disadvantages of various types of control coding [1].

	Type of coding				
Advantages	**Location**	**Shape**	**Size**	**Texture**	**Labeling**
Improves visual identification.	●	●	●		●
Improves non-visual identification (tactual and kinesthetic).	●	❖	❖	❖	
Helps standardization.	●	●	●	❖	●
Aids identification under low levels of illumination and colored lighting.	❖	❖	❖	❖	When trans-illuminated
May aid in identifying control position (settings).		●			●
Require little (if any) training; Is not subject to forgetting.					●
Disadvantages					
May require extra space.	●	●	●		●
May adversely affect manipulation of the control (ease of use).	●	❖	●		
Limited in number of available coding categories.	●	●	●	❖	
May be less effective if operator wears gloves.		❖	❖	❖	
Controls must be viewed (i.e., must be within visual areas and adequately illuminated).					●

❖ Applies to Physical Controls only ● Applies to both Physical and Touch Screen Controls

Adapted from MIL-STD-1472G [1]

Discussion

The table on the previous page notes some advantages and disadvantages of various methods of control coding. The symbols in the table refer to whether the advantage/disadvantage applies primarily to physical controls (e.g., knobs) or both physical controls and touch screens. A defining difference between the two categories is that with touch screens, the user is unable to rest their finger on the control without activation (if a tactile feedback membrane is not incorporated [1]). This quality of touch screens restricts some of the coding applications, such as texture-coding or non-visual control identification. Additionally, some touch screen technologies may not work if the user is wearing gloves [1].

Several sources provide information about spacing and location of controls [2, 3, 4]. In particular, Campbell et al. [4] provides a useful table that summarizes minimum control separation distances for various types of controls. In addition, MIL-STD-1472G [1] recommends that controls that are associated with specific functions should be located in standardized positions across control panels. Although this and other recommendations have been developed for applications in environments other than automobiles, they provide helpful information regarding location coding and avoidance of inadvertent activation of adjacent controls.

Lerner, Kotwal, Lyons, and Gardner-Bonneau [5] recommends that controls for different functions be shaped differently to improve discriminability and to reduce glance times. Shape coding, often used on rotary knobs, may be most effective at increasing identifiability of the control when used in combination with location coding. Shape coding has an advantage in that it has a visual component in addition to a tactile component that can be used to identify the control.

Size coding may not be as useful as shape coding. Size coding is most appropriate, however, in applications using ganged controls. MIL-STD-1472G [1] recommends that no more than three different sizes should be used when coding for absolute size. In addition, when used as coding parameters, knob diameters should differ by at least 1.27 cm (0.5 in) or knob thicknesses should differ by at least 10mm (0.4 in).

Three types of texture coding rarely are confused with one another: smooth, fluted, and knurled. However, different methods and amounts of fluting or knurling may be confused with each other—but not with other types of texture coding [3, 4].

Design Issues

When several controls are similar, they may be difficult to discriminate unless they are separated by an adequate distance. Sanders and McCormick [3] cite a study in which blindfolded participants (which are similar to drivers reaching for controls while keeping their eyes on the road) reached for horizontally and vertically arranged toggle switches. For vertically arranged switches, only a small percentage of errors were made at distances of more than 6.3 cm (2.5 in) from the target switch. For horizontally arranged switches, approximately the same error rate was found at distances greater than 10.2 cm (4 in). Therefore, horizontally arranged switches should be spaced farther apart than vertically arranged switches. Controls may use combinations of coding to facilitate functional associations. For example, rotary controls may be located in horizontal and vertical groups with each group using knobs of a different size [2].

Wearing gloves reduces discriminability of texture-coded controls to varying degrees, depending on the type of texture applied. Knurled knobs are the most difficult to discriminate when gloves are worn. Smooth knobs, however, can still be discriminated from other texture types while wearing gloves [2].

Cross References

Labels for Controls, 9-12

Topic References

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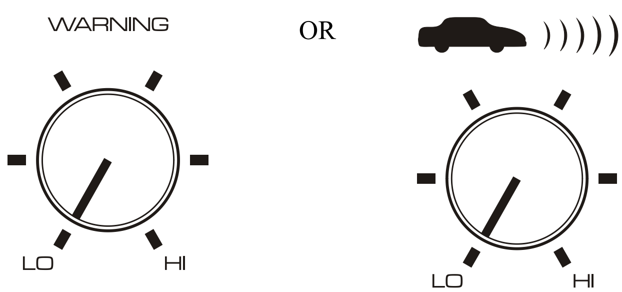
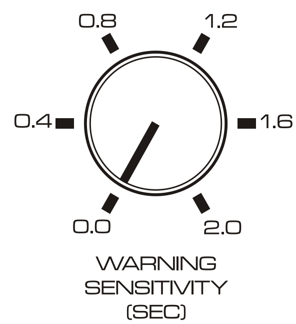
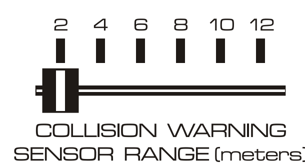
Labels for Controls

Introduction

This topic provides recommendations for identifying controls and control settings using text or symbolic markings.

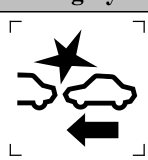
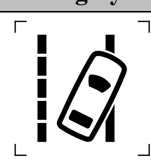
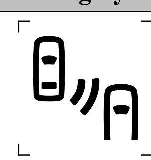
Design Goal: Identify controls with visible, recognizable, and unambiguous labels.
Design Guidance
The best available research on this topic suggests that this design goal can be met when: • Controls are clearly labeled to identify their functions and settings. • Labels are visible and recognizable before the driver reaches for the control, and are positioned so that the driver's hand will not cover the label when reaching for the control. • International standards or recognized industry practices are used for the icons, legibility, words, acronyms, etc. labeling controls and their settings [1, 2]. • Icons are used to represent values. In many cases, numerical values have little or no meaning for the driver. • Controls that regulate a system function over a continuous range clearly identify the limits of that range (i.e., the min and max of the system's allowed settings are identifiable) [3].

Examples of labels for various types of controls.

Preferred	Not Preferred
Forward Collision Warning Sensitivity	
	
Side Collision Warning Sensor Range	
	

Adapted from Pomerleau et al. [4], Campbell et al. [5], and General Motors Corporation [6]

ISO icons for warning systems.

Forward Collision Warning System	Lane Departure Warning System	Obstacle Warning System
		

This excerpt is from ISO 2575:2010 [2], Icon Symbols K.15, K.16 and K.17 on page 46, with the permission of ANSI on behalf of ISO.

Discussion

Labels are probably the most common method of identifying controls. However, they require visual inspection to identify the control, whereas other coding methods do not. Nonetheless, labels should be considered the minimum coding requirement for all controls. Properly chosen labels do not require much learning to comprehend [7]. Labels that conform to internationally accepted standards or recognized human design principles will increase recognition and comprehension of the control, particularly for drivers who use systems from different manufacturers and across international markets. ISO standard 2575 [2] includes a few icons for warning systems. In applications for which no standards exist, relevant design principles or empirical data should be used to determine the appropriate strategy for control labeling [8].

Design Issues

One way to improve comprehension of control function and setting is to label the controls in a manner that is consistent with population stereotypes for control-display relationships [3, 9]. For many control settings, such as warning timing adjustments, numerical labels will have little meaning to the driver. Intuitive labels (e.g., "early" and "late" or graduated icons) provide appropriate feedback to the driver related to the current setting of the control [4].

Labels for control settings may be textual or symbolic; however, symbols are preferred because they are not language-specific, and they can be recognized more quickly than worded messages. In addition, symbols can be represented in more spatially condensed forms, an important consideration in applications where the amount of available space is limited [5, 9].

Text and symbols may be combined to improve comprehension of the control function and settings. For example, Auto Alliance [8] included a variable-function switch for adjusting ACC headway gap and FCW warning sensitivity. Buttons for increasing and decreasing the gap/sensitivity were labeled with up and down arrows, respectively. In addition, these buttons included textual labels ("gap/warn") to indicate the function of the control (see also Campbell et al. [5]).

Since most controls will likely be positioned below the driver's eye height, labels should be placed above the control or in locations that will not be obscured by the hand when operating the control. In addition, labels should be located in a way that allows them to be plainly visible to the driver before reaching for the control. Textual labels should be oriented horizontally whenever possible. Vertical labels—if used—should be read from top to bottom [7].

Cross References

Selecting Character Height for Icons and Text, 6-8; Control Coding, 9-10

Topic References

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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 of the road and their hands off the steering wheel. Additionally, some 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 [1]. However, some research has indicated that voice recognition systems are associated with increased off-road glances [2] 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 uses cognitive resources and, therefore, does not eliminate risk [3]. The precise effects of specific system parameters and implementations of speech input on driver workload and driver performance are largely unknown.

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

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 the 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.
- General Design Goals [3] to consider:
  –Reduce the user's cognitive load to reduce the risk of performing secondary tasks while 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.

Accuracy level of each step	Number of steps required to complete an interaction: 1	2	3	4	5
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 was derived from studies with modest sample sizes, individual interface usability studies, the judgment of experts in the field, or unpublished research results.

Conversation Style: Driver interactions with the system should be paced by the driver [4]. 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 [5]. MIL-STD-1472G [5] 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 [6].

System Feedback: Lumsden [4] 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 [5]. Popp and Faerber [7] 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. These actions relate to adjustments to collision warning systems, which are also not immediately apparent. 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.

Error Handling: MIL-STD-1472G [5] 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) [8]. Additionally, systems should require little user training [5].

General Design Goals: Lumsden [4] 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 as compared to baseline [2].

Design Issues

A simulator study of an in-vehicle speech system [9], found that the recognition accuracy of the system affected lane position, when the accuracy level was very low (44%). 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 [8] 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.

Topic References

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Chapter 10. System Integration

Driver distraction is increasingly identified as key contributing factor in many roadway crashes. Concurrently, in-vehicle, crash avoidance, and wireless technologies continue to develop and expand their presence within the vehicle. Thus, multiple systems are able to present information to the driver and compete for the driver's attention. These different sources of information may occur simultaneously and during periods of increased driver workload.

System integration is the synthesis and incorporation of multiple sources of driver information into the vehicle. It is vital to integrate and coordinate these sources of information so that drivers are not presented with competing and potentially distracting messages while driving. The objective of this chapter is to provide guidance about how to ensure the orderly presentation of information and messages to drivers to maximize the chance that safety-relevant messages will reach the driver in a way that maximizes safety benefits, while, at the same time, ensuring that non-safety-relevant messages enrich the driving experience without distracting the driver in a way that undermines safety.

Topics addressed in this chapter:

- Prioritizing Messages Presented to Drivers
- Using "Master" Warnings in Integrated Warning Systems
- Overview of the HFCV Integration Architecture

Prioritizing Messages Presented to Drivers

Introduction

Message priority is specifically defined as the order of presentation of two or more in-vehicle messages [1]. More broadly, it reflects the relative importance of messages or information items. This topic describes the SAE J2395 Recommended Practice for prioritizing messages and information presented to the driver [1]. For greater depth and detail in using the procedures, see SAE J2395.

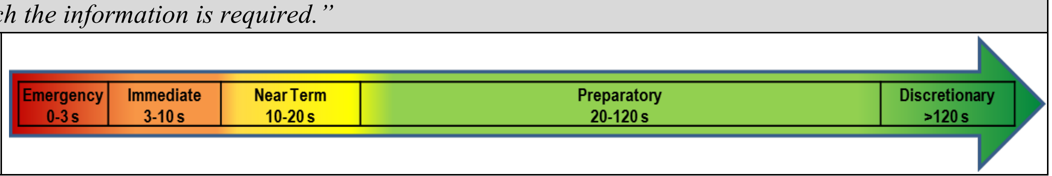
Design Goal: Use an integrated and systematic message prioritization scheme to ensure that drivers are always presented with higher priority messages over lower priority messages.

Design Guidance

The following table reflects SAE J2395 [1] and may be used to determine message prioritization strategies:

Prioritized Driver Need	Action
1.Information requested by the driver	Present immediately, if no other conflict
2.Continuous visual information	Present continuously on a dedicated visual screen
3.Information about the external environment or hazard	Apply safety/operational/time criteria from the Priority Order Index (POI) from SAE J2395 [1]

The three criteria used to determine a message's Priority Order Index (POI) [1].

Criteria	Definition	Examples
1) "Safety Relevance: *The degree to which the information affects the safe operation of the vehicle."*		
Directly Relevant	Direct safety information for decreasing risk of injury or damage to driver, pedestrian, bicyclist, or vehicle.	• Imminent collision warning. • Crash ahead warning.
Indirect/Somewhat Relevant	Indirect safety information that might diminish error, thus decreasing crash risk.	• Route guidance that indicates next turn.
Not Relevant	Information that is not directly or indirectly related to safety or decreasing crash risk.	• Convenience information, such as email notifications, nearby shops or restaurants, etc.
2) "Operational Relevance: *The degree to which the information increases the ease and convenience of the driving task, for example, by decreasing travel time and the stress associated with driving."*		
Highly Relevant	Information related to inconvenience or expense for the driver, such as vehicle damage.	• Notification of incident ahead resulting in traffic delay. • Engine temperature warning.
Moderately Relevant	Information that provides some benefit to the driver (increase ease or convenience), but incurs no cost if not presented.	• Distance to the destination on a navigation system. • The price of a toll ahead.
Little or No Relevance/Significance	Information unrelated to ease or convenience.	• A mobile internet feature. • The "stereo" indicator on an entertainment system.
3) "Time Frame: *Time sensitivity of the information The degree to which the information is time sensitive, that is, the immediacy with which the information is required."*		
Time Categories		

Discussion

Message prioritization is an important consideration as drivers are limited in their ability to attend to messages while engaged in the primary driving task; overloading them with information can lead to driver distraction. Moreover, if a message is warning drivers about an imminent hazard, all other less-important information should be filtered out so that drivers have the best opportunity to receive and act on the critical message. At a very general level, the prioritization approach described herein orders messages according to: (1) immediate crash and hazard information, (2) safety and operational messages that are not urgent, but are time/location dependent, and (3) convenience information.
The SAE process [1] for determining the POI involves multiple steps, including:

1. Select a group of at least three prioritization evaluators that can objectively evaluate messages.
2. Describe individual messages in terms of their basic "information units", which are the smallest useful piece of information that can stand alone in both meaning and context.
3. Filter the messages using the flow diagram described in the design guidance.
4. Have the evaluators to determine the POI for each message using the criteria in the previous table. Results should be discussed, and final POI ranks averaged across evaluators.

Note that SAE J2395 [1] frames the Safety Relevance criterion in terms of how direct the link is between the information and potential hazards or increased crash risk. Crash-risk severity is not a consideration. This presents a challenge for arbitrating the relative priority of high-priority imminent crash messages (e.g., forward crash warning [FCW] versus blind spot warning [BSW]). ISO 16951 [2] guidance on message prioritization does take safety risk into account, and may be helpful in this regard. Specifically, ISO 16951 [2] characterizes safety-related messages in terms of criticality, such as the degree to which harm might result if the message is unheeded. There are four levels of criticality, including: (1) severe or fatal injury, (2) injury or possible injury, (3) no injury but vehicle damage likely, and (4) no injury and no vehicle damage. ISO does not separately identify Operational Relevance as a criterion, instead incorporating this aspect into criticality.

Information items that are prioritized based on the POI should correspond in time with roadway, traffic, and environmental events in a way that is consistent with how driver should use the information. For example, hazard information should be presented immediately, whereas route guidance information should be presented far enough in advance for drivers to comfortably prepare for the upcoming maneuver. Other information that is not time dependent (i.e., discretionary) can be presented during information "down times," when drivers have no other information requiring their attention. An exception to this would be Discretionary messages that have a high Safety and Operational relevance (e.g., flooded or closed roads ahead), in which drivers should receive the message with sufficient time to change their route. Note that there is currently no information about how frequently drivers can be presented with low priority messages before they get annoyed. It may be necessary to provide drivers with the capability to control minimum presentation time for convenience messages, or disable them entirely.

Design Issues

There is no accepted protocol for integrating aftermarket or nomadic systems. Even if an aftermarket system connects directly to an integrated system, POI provided by the aftermarket system may be unreliable or undefined and may not contain the appropriate POI. Also, the ISO and SAE approaches may only provide a good starting point for prioritization and may be less useful for difficult display conflicts (e.g., prioritization of different imminent crash warnings [ICWs]).

Little research specifically addresses how to effectively disengage drivers from secondary tasks when higher POI messages are presented. Holmes et al. [3] conducted an on-road study to measure the impacts of various ways to interrupt tasks in a connected vehicle environment. The results showed that measures such as the time to complete the task, the length and frequency of glances to the display, eyes on road time, and driver preferences for the method of interruption were influenced by a host of variables, including driving context and environment, driver age, message type (i.e., safety versus non-safety), and driver type (i.e., passenger vehicle versus heavy vehicle).

Cross References

Priority Order Index Look-up Table for Message Prioritization, 12-19; Tutorial 2: Priority Order Index Look-up Table for Message Prioritization

Topic References

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Using "Master" Warnings in Integrated Warning Systems

Introduction

This topic provides information about the relative advantages and disadvantages of using master warning schemes (a single alert for multiple safety applications) in comparison to separate and distinguishable messages for each safety application. The use of "master" warnings leads to the possibility that drivers could be unclear or even confused about the nature of the hazard associated with the warning, as well as about a proper response to the hazard. This reflects three factors: (1) the physical similarity of warnings across applications, (2) the fact that these applications address hazards in the same location relative to the driver, and (3) the possibility that some of the hazards may not be directly perceivable by the driver. Overall, this could result in drivers making the wrong response, or unnecessarily delaying a response because they required more time to determine the nature of the hazard. This issue is a concern regardless of whether or not concurrent warnings are being presented to the driver (e.g., simultaneous FCW and BSW warnings), although such a situation could compound the problem.

Design Goal: Design hazard warnings to support a timely and accurate response by drivers.

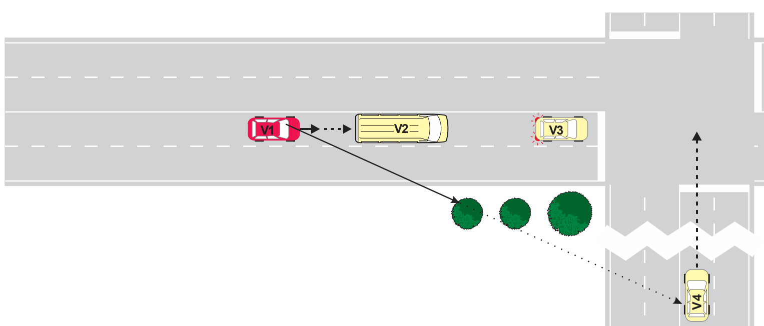
Design Guidance

The best available research on this topic suggests that, in situations where multiple integrated safety systems are present and/or hazards may be difficult to perceive or detect, DVI effectiveness may be aided by :

- Securing and orienting driver attention to the immediate driving situation and any potential hazards.
- Placing a low memory-recall load on the driver.
- Providing sufficient distinctiveness across the warnings such that drivers can quickly identify the nature and location of the hazard and decide on a response.

Master warnings could lead to driver confusion.

If a single, master alert is used in a vehicle equipped with multiple safety systems (such as a hypothetical connected vehicle [CV] with forward crash warning [FCW], emergency electronic brake light (EEBL), BSW, do not pass warning [DNPW], and intersection movement assist [IMA] safety systems), the driver could be confused about the nature of the hazard as well as the proper response. The figure and table below describe how a single hazard warning can potentially lead to confusion between two different system messages.



Systems	Scenario Shown in Figure	Potential Driver Response Confusion
EEBL & FCW	EEBL with variable space between V2 and V3.	EEBL can require high or low level of deceleration depending on V2-V3 spacing, but likely requires hard braking with FCW.
IMA & EEBL/FCW	IMA hazard for V1 when V1 is in a platoon traversing an intersection at speed.	Driver may misinterpret IMA as FCW or EEBL if they cannot see IMA hazard, and miss opportunity to alter collision trajectory with V4.
DNPW & FCW	V1 preparing to pass V2 while V2 decelerates unexpectedly.	Driver may misinterpret FCW as DNP and be delayed in braking for V2.
BSW & FCW	V2 brakes while V1 driver doing shoulder check (but no adjacent vehicle present)	Driver may misinterpret FCW as BSW even though the adjacent lane is clear. Driver would miss an opportunity to get out of the lane (or might return to lane) of the FCW hazard.

Discussion

From a design perspective, the competing design approaches and trade-offs associated with “specific versus master” warning approaches are fairly straightforward. Single master alerts reduce the need for drivers to recall individual “warning-hazard” pairings; they primarily serve to orient and direct drivers’ attention to the external scene, where they can then identify the specific nature of the hazard and determine an appropriate response. Multiple alerts, specific to a hazard, are coded cues that require drivers to successfully recall (or infer) the unique “warning-hazard” relationship (although driving context and awareness of their situation may help), but may give drivers useful information that they can use as they identify hazards and decide on a response.

The empirical research in this area is limited and far from consistent with respect to findings and design recommendations. In particular, there is relatively little guidance in the literature regarding specific requirements for distinctiveness of alerts in systems with large numbers of applications or for alerts with novel applications such as EEBL. Brown et al. [1] provided design criteria that argued for maintaining distinctive warnings; these criteria were derived from research indicating that distinct warnings are more effective than a system with a single, master warning [2] and may lead to higher levels of driver acceptance [3]. The literature, though, is not conclusive, as some studies [4] suggest that a single master alert may be sufficient to induce drivers to look up and assess the situation; however, the situation may not be clear if the driving environment lacks visual cues that indicate the nature of the hazard. This exact concern was evaluated by Thoma et al. [5] in a simulator study that examined driver comprehension and response times to specific versus master alerts in situations where the hazard was easy to detect and in others where it was difficult to detect. Though the study clearly has some limitations, performance in situations where the hazard was difficult to detect was better with the specific warning.

A critical limitation in all of the research we have examined is the application-specific nature of the conclusions (a limitation frankly expressed in Cummings et al. [4]). In short, the broad applicability of even the few studies relevant to this issue is constrained by the number and nature of the specific applications under investigation. For example, Chiang et al. [2] only looked at FCW and LCW systems, while Cummings et al. [4] only looked at FCWs and lane departure warnings (LDWs). For more recent applications (e.g., EEBL, IMA, and DNPW), as well as unique combinations of applications (e.g., FCW with DNPW and EEBL), there is insufficient evidence in the literature to say conclusively whether or not distinctive warning presentations would improve drivers’ responses. Consequently, the most appropriate approaches for determining which warnings should be distinctive between various applications and where master alerts would suffice is unclear.

Design Issues

In general, the DVI design community may need to consider other options beyond the “single versus multiple” alert paradigm and recognize that neither approach is likely to be optimal for all combinations of safety applications. Under many very possible warning scenarios, single/master alerts are unlikely to carry enough information about the location or nature of a hazard and could lead to driver confusion and errors, and (under these same circumstances) there can be too many unique “warning-hazard” combinations possible for drivers to be able to recall them and act in a timely fashion.

Cross References

Multimodal Warning Messages, 4-4; Warning Stages, 4-6

Topic References

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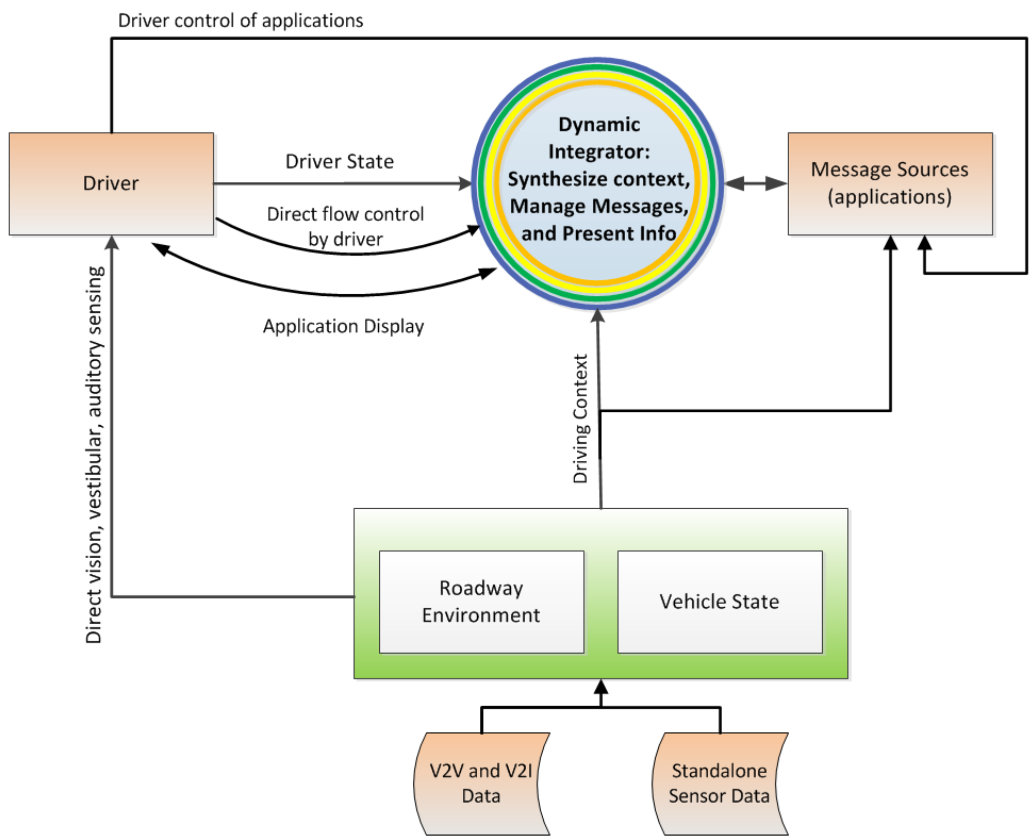
Overview of the HFCV Integration Architecture

Introduction

This topic presents a *HFCV Integration Architecture* developed in support of research into vehicle-to-vehicle (V2V) technology. This architecture governs delivery of information to the driver so that safety-relevant messages are presented in a timely and effective manner. An integrated system, which thoughtfully controls the presentation of both safety-relevant and non-safety-relevant messages to the driver, may increase safety by mitigating potential consequences of increased information flow; such as overloading or inappropriately distracting the driver's attention from the primary task of driving [1]. As V2V research continues, this integration architecture may help support managing the information that is presented to a driver during periods of increased workload. Tutorial 3 presents more information on this topic.

Design Goal: Manage the presentation of information to the driver so that safety-relevant messages are presented in a timely and effective manner.
Design Guidance
The Integration Architecture identifies three integration processing stages (see next page for details): • Synthesize Inputs (synthesize contextual information) • Manage Messages (arbitration through filtering, prioritizing, and scheduling) • Present Information (cleared information is presented the driver)

Context diagram for V2V integration process.



Doerzaph et al. [1]

Discussion
From Doerzaph et al. [1, see Tutorial 3 in this document], the figure on the previous page provides a context diagram that illustrates the flow of information sources into the Dynamic Integrator (indicated by the multi-colored, multi-ringed circle). The integration process ensures that messages are delivered to the driver with a controlled strategy, thus reducing the likelihood that a safety-relevant message goes unnoticed by the driver or that it is perceived as less critical, and increasing the likelihood that messages in general are provided in an appropriate manner (e.g., do not overload the driver).

The figure outlines the basic problem space, indicating that successful integration may incorporate knowledge of:

- The vehicle state (e.g., speed, fuel levels, tire pressure, oil pressure, etc.).
- Roadway environment (including CV data originating from ambient traffic and roadside information sources (e.g., trajectories and number of adjacent vehicles, proximate lane closures, traffic movement, work zone configuration).
- Driver state (e.g., alertness level) and interactive input (e.g., information requests, preference settings).
- Messages originating from applications that seek to present both solicited and unsolicited information to the driver.

Key steps in the integration process include:

Synthesize Inputs: In this step, details of context are determined through a synthesis of various driver, roadway environment, and vehicle data. This data may be used by the integrator to make informed decisions during the *Manage Messages* and *Present Information* processes detailed below. Generally, the data will be synthesized to estimate the driver's ability to safely perceive, recognize, and respond to the message. Such an estimate may be based on a variety of measures, such as traffic density, speed, last interaction with the DVI, radius of roadway curvature and, perhaps, direct driver monitoring systems when available. Additional inputs synthesized may include, but are not limited to, the driver's configured integration and application settings (discussed previously) and perhaps any regulatory information that could influence when particular types of messages are permitted.

Manage Messages: The *Manage Messages* step is at the heart of the Dynamic Integrator and, during this task, messages are arbitrated to determine which might be filtered (i.e., discarded), dynamically adjusted in relative priority, and scheduled for presentation to the driver. Messages that are not appropriate given the current driving context may be immediately filtered out. Filtering will occur based on user settings or when driving conditions indicate it is unsafe to provide a given type of information content. When multiple messages are cleared by the filter, a prioritize process will determine the relative importance of the messages and assign presentation order accordingly. Priority ordering itself, however, does not determine when a message will be presented. Timing is the function of the scheduling process which assesses the metadata and context information to determine when each message should be presented. This process controls message cadence and ensures that drivers have the capacity to receive information while focusing on the primary task of driving. In some cases, the schedule process may allow certain high-priority messages to interrupt lower priority messages (e.g., in the case of an imminent safety warning).

Present Information: In this step, messages that have been cleared for delivery are analyzed and distributed to the appropriate DVIs for information rendering. The *Present Information* process tracks the use of all DVIs and publishes the information for the applications and *Manage Messages* processes to use. This status information contains details of which applications are currently using the DVI and, when allowed by designers, which types of other applications may share access. For example, consider a navigation application which is displaying map content across the large center stack screen. The *Present Information* process may have provisions for allowing a small overlay to appear in the screen corner which may, for example, display the current speed limit as populated from an in-vehicle sign application.

Design Issues

This design guidance, as well as Tutorial 3, presents a proposed HFCV Integration Architecture model to be considered by engineers, system developers, and designers in the development of future V2V systems. They are not intended to represent the only approach to integration but, rather, to demonstrate an example approach that may be leveraged by designers.

Cross References
Tutorial 3: Preliminary HFCV Integration Architecture, 12-21

Topic References

1. Doerzaph, Z., Sullivan, J., Bowman, D., & Angell, L. (2013). *Connected vehicle integration research and design guidelines development: Integration architecture, Task 5* (Report under Contract No. DTNH22-11-D-00236/0001). Washington, DC: National Highway Traffic Safety Administration.

Chapter 11. Application of Human Factors Design Guidance to Heavy Vehicle DVIs

This chapter provides information regarding special considerations that must be taken into account when designing collision warning interfaces for use in heavy vehicles—specifically, heavy trucks and transit buses. In general, the design guidance for passenger vehicles also applies to heavy vehicles; however, the unique driving environments and driver tasks associated with driving heavy vehicles require additional consideration when designing warnings for these vehicles. Vehicle characteristics that must be considered for both heavy trucks and buses include vehicle size and weight, braking distance, and limitations to visibility and maneuverability, while differences between heavy trucks and buses include driver tasks and passenger considerations. Although the available literature for warning designs in heavy vehicles is relatively sparse for most topics, this chapter provides DVI design guidance that addresses these issues and considerations.

Topics addressed in this chapter:

- Design Considerations for Warning Signals in Heavy Vehicles
- Selection of Sensory Modality for Heavy Vehicle Warnings
- Design Guidance for Visual Displays in Heavy Vehicles
- Visual Display Location in Heavy Vehicles
- Design Guidance for Auditory Displays in Heavy Vehicles
- Design Guidance for Haptic Displays in Heavy Vehicles
- Driver Controls for Collision Warning Systems in Heavy Vehicles
- General DVI Considerations for Heavy Vehicles

Design Considerations for Warning Signals in Heavy Vehicles

Introduction

This topic provides information regarding special considerations for designing collision warning system (CWS) signals for use in heavy trucks and transit buses. CWS for these vehicles must consider the substantially larger size, heavier weight, and different handling characteristics than passenger vehicles in their design. Also, they generally are noisier and vibrate more than passenger vehicles, and the tasks required to drive these vehicles differ from those in passenger vehicles. These factors must be considered when designing CWS in heavy vehicles.

Design Goal: Design warning signals that accommodate the size, weight, and driving conditions unique to heavy trucks and buses.

Design Guidance

The literature suggests that these characteristics may be used in support of the design goal:

Warning Timing and Levels

- Heavy vehicles may require longer braking distances; advanced warning to facilitate longer headway or time-to-collision may be needed as compared to passenger vehicles.
- Multi-stage warnings may help provide sufficient warning time to avoid hard braking and high deceleration.

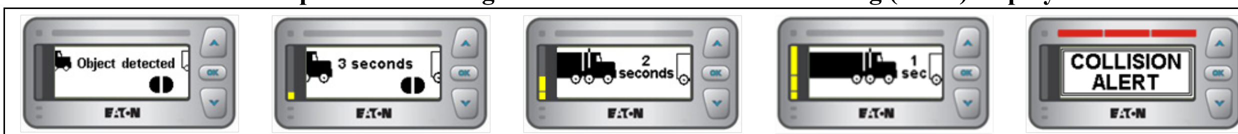
Warning Signal Directionality

- Information about the direction of a hazard may aid drivers, especially in systems that integrate multiple detectors.

Warning Signal Intensity

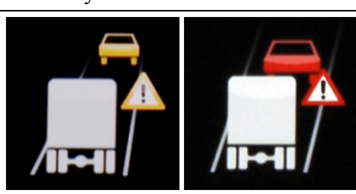
- Visual warning signals are most detectible when they have an adequate range of intensities to be visible and salient under varying ambient illumination and glare.
- Auditory signals are most detectible when they are sufficiently intense to overcome high levels of ambient noise and adaptable to large fluctuations.
- Haptic signals are most detectible when they are sufficiently intense and/or have sufficient temporal characteristics to be readily discriminated from ambient vibrations in the cab.

Examples of multi-stage visual forward collision warning (FCW) displays.



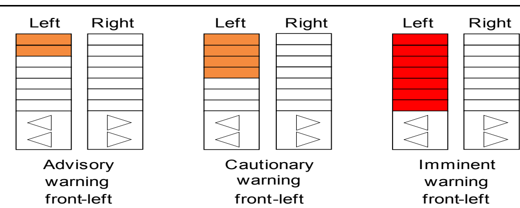
Adapted from Brown et al. [1]

Graded forward crash warning (FCW) warning from the Integrated Vehicle-based Safety System (IVBSS) field operational test (FOT) provides fine-grained information regarding the diminishing headway. Yellow bars on the left of the display indicated graduated levels of urgency for cautionary warnings (center three images) and a red bar across the top of the display indicated a highly urgent, imminent warning condition (right). The visual alert was accompanied by an auditory signal that increased in urgency as headway decreased.



From Stephens et al. [2]

Two-stage warning showing cautionary (left) and imminent (right) collision warnings. The level of urgency is indicated by the color of the icon and the proximity of the lead vehicle to the truck. Amber is used to indicate lower urgency (left), and red is used to indicate higher urgency (right). The visual alert was accompanied by an auditory signal that increased in urgency as headway decreased (one cautionary and two imminent levels).



Adapted from UCPATH & CMURI [3, 4]

This is a visual display that provides progressive warning levels. Amber illumination is used for advisory and cautionary warnings, and red illumination is used for imminent warnings. The number of illuminated bars corresponds to the relative time-to-collision (TTC), with more light emitting diodes (LEDs) illuminated as the TTC becomes shorter [3,4].

Discussion

The potential differences in stopping distances between heavy vehicles and passenger vehicles require that heavy vehicles travel with longer headways when following passenger vehicles in order to avoid rear-end collisions. Consequently, FCW device thresholds must provide earlier warnings to heavy-vehicle drivers than those provided to drivers of passenger vehicles. This requirement has led to recommendations that heavy truck crash warning systems (CWSs) should use progressive (i.e., multi-stage or graded) warnings to provide drivers with sufficient warning time to avoid forward crashes [5]. Similarly, a multi-stage collision warning is recommended in transit buses [6] in order to avoid hard braking and the resulting abrupt deceleration to unrestrained passengers.

Information about the direction from which a hazard is coming is important, especially in systems that integrate multiple detectors. Drivers of heavy vehicles will most likely benefit from having additional information regarding the location of a detected hazard made readily apparent to them. Reinach and Everson [6] identified the requirement that transit bus collision warnings indicate the direction of the hazard. In a transit bus implementation [3], an integrated CWS display used bars and arrows to indicate the side of the bus from which the forward and side hazards were detected.

Design Issues

Highly variable ambient lighting, including the use of passenger lighting, was identified as a design issue for transit bus CWS designs in Houser et al. [5]. Sun glare was also identified by transit bus drivers following their exposure to a prototype CWS visual display [4]. These drivers indicated they had difficulty seeing the visual displays when driving directly into the sun, a condition in which they felt having an FCW system would be highly beneficial. Because of the potential for reduced visibility of visual displays, it is recommended that redundant signals of a second modality be used to increase drivers' awareness of the situation.

Auditory signal strength must be sufficient to overcome ambient noise levels in a manner that does not startle the driver. Noise levels in heavy vehicles vary, but are typically louder than those of passenger vehicles [7]. Design guidance in Lerner, Kotwal, Lyons, and Gardner-Bonneau [8] identified the issue of potentially high noise levels in heavy trucks, noting that such conditions could be addressed through the implementation of automatic, adaptive control of intensity. An overly loud signal can induce an inappropriate (e.g., startle) response, potentially resulting in abrupt or hard braking by the transit bus operator [5].

Haptic signals have traditionally been considered inappropriate for use in heavy-vehicle environments because they could potentially be masked by ambient vibrations in the cab. Recent research [9], however, suggests that properly designed vibrotactile signals in the seat pan can be detected in heavy-vehicle environments and that transit bus drivers prefer them because the signals do not overload visual and auditory perceptual channels. Some drivers considered steering torque signals to be inappropriate because they were uncomfortable with something else having control over the steering or because it prompted them to steer at times when a steering response was inappropriate.

Cross References

Visual Warnings, Chapter 6; Auditory Warnings, Chapter 7; Haptic Warnings, Chapter 8

Topic References

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6. Reinach, S. J., & Everson, J. H. (2001a). Driver-vehicle interface requirements for a transit bus collision avoidance system (SAE Paper No. 2001-01-0052). *Society of Automotive Engineers 2001 World Congress.*
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Selection of Sensory Modality for Heavy Vehicle Warnings

Introduction

This topic provides information to support the selection of sensory modality (i.e., visual, auditory, or haptic) for presenting messages in a heavy-vehicle environment. Factors that influence the choice of modality in heavy-vehicle applications are largely the same as in passenger vehicles, with a few notable exceptions related to driver's visual scanning behaviors, long-term exposure to alerts, and passenger considerations. The information in this topic will help designers determine which presentation modes are most appropriate for various messages.

Design Goal: Select DVI modalities consistent with heavy-vehicle driver tasks, needs, and expectations to support a timely and accurate response by drivers.

Design Guidance

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

- Avoid using exclusively visual warnings for imminent collision warnings.
- Use an auditory or haptic signal in conjunction with a visual display to increase warning conspicuity. Auditory signals have been shown to provide effective cautionary and imminent warnings, particularly as part of multimodal warnings.
- Use auditory or haptic signals as the primary mode of conveying collision warning information.

The use of haptic signals may be preferred over auditory signals in transit bus applications because they are less obtrusive and less likely to be noticed by passengers. However, haptic signals have additional considerations to ensure they are perceived. See *Design Guidance for Haptic Displays in Heavy Vehicles* (page 11-12) for issues, caveats, and recommendations associated with using haptic signals in heavy vehicles.

The following table provides general recommendations regarding auditory, visual, haptic/tactile, and multimodal display of CWS status information, cautionary warnings, and imminent warnings for heavy trucks and transit buses.

Warning types and suggested modalities.

Warning Modality	CWS Warning Type		
	Status Information	Cautionary Warning	Imminent Warning
Auditory	A neutral, generic tone can be used to alert the driver to the presence of status information.	An alerting tone or earcon can be used to alert the driver to the presence of more specific cautionary information.	An attention-demanding tone can be used to immediately direct the driver's attention to an imminent hazard in heavy truck applications.
Visual	A readily interpreted written message or icon can be used to visually convey system status information.	An appropriately located visual signal can be used to convey the relative level of the present hazard and direct the driver's attention toward that hazard.	An appropriately located visual signal can be used to convey the imminent nature of the warning and direct the driver's attention toward that hazard.
Haptic/Tactile	Not recommended.	Evaluation of adequate driver comprehension, timely response, and driver annoyance would be required prior to implementation.	Evaluation of adequate driver comprehension and timely response would be required prior to implementation.
Multimodal	A multimodal auditory annunciator coupled with a visual icon or message is the most commonly recommended means of alerting and conveying CWS status information.	A multimodal auditory alert coupled with an immediately recognizable visual icon or indicator is the most commonly recommended cautionary warning.	An auditory alert coupled with an immediately recognizable visual icon or indicator is the most commonly recommended imminent warning for heavy truck applications.

Discussion

Because heavy-vehicle drivers perform continual visual scanning (e.g., the "keep your eyes moving" principle for heavy-vehicle operation from the Smith System training program [1]), the amount of time drivers allocate their visual attention to any given location is intentionally limited. Consequently, the time between glances to a visual warning display imposes a potential delay in perceiving its visual warning, which means drivers may not always attend to an exclusively visual imminent crash warning (ICW) with sufficient timeliness.

Existing evidence supports the use of bimodal information displays (e.g., simultaneous auditory and visual) to enhance responses in heavy vehicles. In Belz, Robinson, and Casali [2], bimodal displays (e.g., auditory and visual) for heavy truck FCW and lane change warning (LCW) resulted in faster brake response time and lower crash rates (respectively) than a visual-alone or auditory-alone displays. DVI design requirements for transit buses [3] suggest that multimodal warnings would be required in transit bus CWS due to the presence of a high amount of mechanical vibration and ambient auditory noise, in combination with the high visual demands of the job. The use of bimodal warnings could be problematic for specific systems under conditions associated with a high false alarm rate. An integrated collision warning system for urban bus operations that was tested under controlled conditions by UC-PATH and CUMRI only achieved a 65 percent and 35 percent correct warning rate for *alert* and *imminent* warnings, respectively [4]. Bus operations can occur in dense urban areas, which require operators to operate close to vehicles and pedestrians, resulting in the need for highly reliable warning thresholds as well as selection of the most appropriate presentation modality.

Haptic signals have traditionally been considered inappropriate for use in heavy-vehicle environments because they could potentially be masked by ambient vibrations in the cab; however, research is emerging that suggests haptic signals may be useful in some applications. In a survey of Subject Matter Experts (SMEs) [5], SMEs indicated that heavy truck designers have made improvements to cabs by way of reduced noise and vibration and that these improvements may make haptic signals a viable option for collision warning systems. Recent research [6] supports the use of haptic displays in transit buses, suggesting that properly designed vibrotactile signals in the seat pan can be detected in heavy-vehicle environments and that transit bus drivers prefer them because the signals do not overload visual and auditory perceptual channels. Advantages of haptic displays also include not attracting passenger attention, providing a natural transition from warning to system control, and retainment of conspicuity under glare and high ambient noise [7]. Some drivers untrained with the CWS, however, may mistake the brake pulse as a vehicle malfunction [8]. Therefore, a brake-pulse display should be carefully evaluated before use.

Design Issues

The results from Belz et al. [2] should be taken with caution as their study conditions limit the generalizability of their results. Driver workload was not measured or manipulated, which would have allowed for a more meaningful comparison to actual truck driving, where workload may be quite substantial due to the complex nature of operating a heavy vehicle.

Cross References

Multimodal Warning Messages, 4-4; Visual Display Location in Heavy Vehicles, 11-8; Design Guidance for Auditory Displays in Heavy Vehicles, 11-10; Design Guidance for Haptic Displays in Heavy Vehicles, 11-12;Driver Controls for Collision Warning Systems in Heavy Vehicles, 11-14; General DVI Considerations for Heavy Vehicles, 11-16

Topic References

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Design Guidance for Visual Displays in Heavy Vehicles

Introduction

Chapter 6 provided design guidance for visual displays; this topic provides an overview of additional factors that may be considered for selecting and designing displays for heavy-vehicle applications. The design goals and design guidance presented in Chapter 6 are generally applicable to the heavy-vehicle environment; the information below provides some caveats and additional considerations. In general, the greater workload and visual complexity associated with the heavy-vehicle driving environment suggests caution when adding new displays or when presenting new information to the driver.

Design Goal: Select visual displays and visual display characteristics that accommodate heavy-vehicle driver workload environment constraints.
Design Guidance
The literature suggests that these topics and considerations may support the design goal: There are a number of issues and principles that are unique to heavy vehicles with regard to the location of visual displays. General guidance for the location of a visual display is discussed on page 6-4. Considerations for heavy truckes are discussed more comprehensively on page 11-8 (*Visual Display Location in Heavy Vehicles*). There are no known or obvious revisions with respect to heavy vehicles for the use of the design goals or design guidance presented in the following Chapter 6 topics: • Visual Display Type for Safety-related Messages (page 6-2) • Using Color (page 6-6) • Selecting Character Height for Icons and Text (page 6-8) • Temporal Characteristics of Visual Displays (page 6-12) • Display Glare (page 6-14) • Head-up Displays (page 6-16)

Discussion

The heavy-vehicle (HV) cab visual environment presents special challenges to the HV driver who must continually monitor the roadway and traffic while controlling the truck on the road. For example, the workload demands of HV driving are typically viewed as higher than passenger vehicles, due to more complex vehicle control operations (steering, shifting, and braking) and the need to adjust to potential hazards sooner because of longer braking times. One advantage that HV drivers have in terms of the cab visual environment is that they sit higher than passenger car drivers. As a result, they can see farther when there are vertical sight restrictions, such as hillcrests. This may permit truck drivers to see traffic conditions or objects in the road sooner and, therefore, begin braking sooner.

One important aspect of the visual environment that is intended to be addressed by side-looking collision warning systems is the visual blind spots that surround an HV. Because of the location of the driver and configuration of the tractor and trailer, HV blind spots are not symmetrical on either side of the vehicle, with the driver's right side having more extensive unobservable areas. The extent to which visual blind spots can be attenuated through the use of fender-mounted mirrors is an important consideration. In a study comparing early LCW systems, Mazzae and Garrott [1] found that fender-mounted mirrors provided blind spot coverage superior to any other side object detection system that they tested. Later work performed by Fitch et al. [2] examining a camera-based system providing side and rear blind-spot views to heavy truck drivers indicated no significant increase or decrease in safety-critical event involvement.

Imminent collision warnings for FCW and LDW are an important design issues in heavy vehicles. Design guidelines for these systems [3] recommend that all such warnings that have priority for display should include a secondary visual mode that supports rapid identification of the nature and location of the hazard and requires a minimal—or no—glance time away from the imminent roadway hazard. An assessment of an ICW-only HV forward collision warning system indicated that approximately half of drivers will look towards the instrument panel area during an alert [4]. In general, the recommended visual display is a symbol/icon stimulus that is easily recognized as an FCW indicator.

The use of HUDs in a heavy-vehicle environment has not been studied extensively. In general, head-up displays (HUDs) have the potential to provide drivers with critical information while minimizing glance times away from the forward roadway scene. While the design guidance on pages 6-16 and 6-17 can generally be applied to heavy vehicles, some caution is warranted. In a transit bus application [5], 40 percent of drivers considered the HUD to be distracting, commenting that the HUD increased workload and often did not provide sufficient benefit to warrant its use. Note that this finding could have been related to the specific implementation of the HUD.

Design Issues

In general, designers of heavy-vehicle DVIs should be sensitive to the many unique driver, task, and environmental considerations that might impact the development of safe and effective HV DVIs. Lichty et al. [6] conducted interviews with designers of HV DVIs to determine their unique needs and wants for DVI information. Specific heavy-vehicle characteristics that were believed to impact the design of visual displays include posture, greater anthropometric range, low tolerance for false alarms, higher workload (including additional primary tasks such as monitoring route, road restrictions, weigh stations, communications with dispatchers), and greater existing complexity of the in-cab environment (e.g., up to 52 tell-tales already exist in most heavy vehicles).

Cross References

Chapter 6

Topic References

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Visual Display Location in Heavy Vehicles

Introduction

Visual warnings must be seen to be effective, and the location of a display plays an important role in its visibility. The design guidance on page 6-4 for *Locating a Visual Display* is relevant because the locations that passenger and heavy-vehicle drivers scan are similar, but there are a few differences. This topic addresses issues that are unique to heavy vehicles with regard to the location of visual displays.

Design Goal: Place the primary visual interface in a location that facilitates rapid extraction of information without obstructing the forward view or the view in the mirrors.

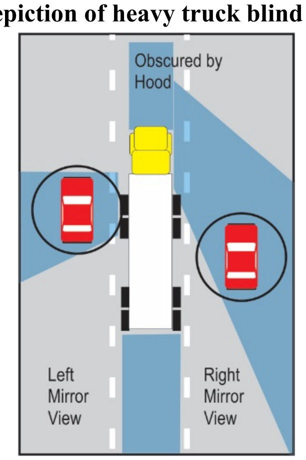
Design Guidance

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

- Display location is compatible with normal visual scanning behaviors that heavy-vehicle drivers are trained to perform.
- LCW/blind spot warning [BSW] primary displays are aligned with the driver's line of sight to side-view mirrors.
- Visual collision warnings are not provided within the instrument panel of heavy vehicles.
- Visual displays are not placed in locations that can obstruct mirrors or the forward scene.

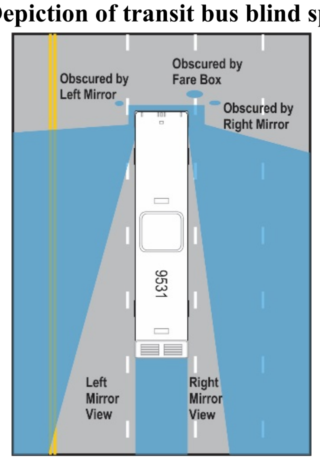
Heavy vehicle drivers typically allocate much of their visual resources to scanning the forward roadway and viewing their mirrors to maintain awareness of lateral hazards. Visual warning displays for hazards in blind spots are best presented in close proximity to the relevant mirror (e.g., near the left mirror for left BSW). The two upper frames in the figure below depict typical blind spots for heavy trucks (adapted from FMCSA [1]) and transit buses (adapted from Thorpe et al. [2]). The two lower frames of the figure depict results of on-road studies of heavy-vehicle driver glance times, providing drivers' general allocation of visual resources in heavy trucks [3] and transit buses [4].

A. Depiction of heavy truck blind spots.



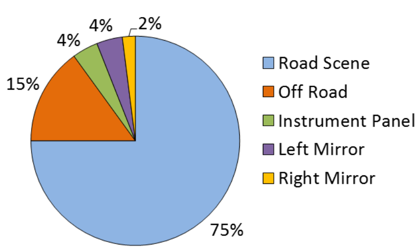
Adapted from FMCSA [1]

B. Depiction of transit bus blind spots.



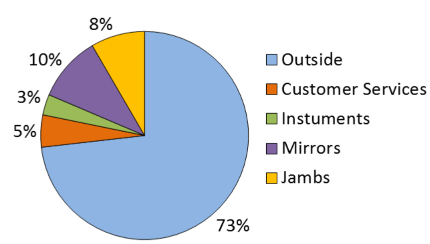
Adapted from Thorpe et al. [2]

C. Heavy-truck driver allocation of visual resources.



Data from Tijerina et al. [3]

D. Transit bus driver allocation of visual resources.



Data from Göbel et al. (1998). Stress and strain of short haul bus drivers: Psychophysiology as a design oriented method for analysis. *Ergonomics, 41*(5), Taylor & Francis Ltd. [4]. Reprinted by permission of the publisher.

Discussion

Studies of overall visual allocation and individual glance times of heavy truck drivers [3] and transit bus drivers [4] indicate that over 73 to 90 percent of glances during driving are directed outside of the vehicle (road scene, off road or outside). These sources also indicate that heavy-vehicle drivers allocate approximately 10 percent of glance times to mirrors for glances that are typically less than 1 second during driving. These findings suggest that FCW visual displays should be mounted in or near the forward line of sight and LCW, BSW, and side collision warning (SCW) visual displays should be mounted in or near the side mirror line of sight.

Driver glances to the instrument panel by heavy-vehicle drivers appear to be limited in both frequency and duration. The available data suggest that heavy truck drivers allocate between 2 percent and 4 percent of their total visual glance time to looking at the instrument panel [3]. Similarly, 3.2 percent of total glance time in transit buses [4] was estimated to be spent looking at the bus instrument panel. These findings suggest that visual warning displays should not be located in instrument panels; however, the instrument panel is an appropriate location for controls and status displays, especially if an auditory status warning is provided to orient the driver to the display.

Although some sources have raised concerns regarding passenger disturbances from warnings [5, 6], these concerns have not been found in revenue-generating operations with customers. The primary concern of warning presentation is safety. The best guidance possible given the current state of knowledge is to present the safety information to the driver in accordance with existing principles and, if possible, consider ways to minimize passenger disturbances.

Design Issues

Finding a suitable location to mount a visual display can be challenging in a heavy-vehicle cab where the available space for mounting the display is limited. One strategy for locating a display in such a cab is to integrate the display into an existing multifunction, central information, or hybrid/reconfigurable display used in the vehicle [7]. The high position of instrument panels of some heavy trucks and motorcoaches may provide a position meeting display location criteria [8]. If this approach is taken but the location does not meet the criteria for optimal visibility, the visual warning should not be the sole mode of presentation. The visual display can provide redundant or supporting information to an auditory warning.

HUD visual elements need to be as simple as possible. An assessment of an integrated bus driver assist system that consisted of a warning system that had a HUD with a high degree of visual complexity, in addition to redundant tactile warnings and warnings from a tertiary visual display that showed a birds-eye view of the bus and surrounding obstacles is described in Pessaro and Nostrand9. The visual complexity of the HUD resulted from the presentation of conformal images that overlaid all vehicles and pedestrians located within range of the on-board sensors. In addition, the overlay images were color coded to provide multi-stage warnings for pedestrians and vehicles. The assessment found 40 percent of drivers considered the HUD distracting, a source of increased workload, and often not providing sufficient benefit to warrant its use [9]. If HUDs are used to provide warnings, the images and content need to be visually simple (see *Message Complexity*, page 5-4).

Visual displays must not obstruct drivers' visibility of the forward scene or of the mirrors. SMEs have expressed concern that an improperly-positioned display in the A-pillar could obstruct the view of the mirrors and increase the size of blind spots [7]. Similarly, dash-mounted displays can obscure areas of the forward view if improperly placed. Display location must avoid the occlusion of important visual information in the driving environment.

Cross References

Message Complexity, 5-4; Locating a Visual Display, 6-4

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Design Guidance for Auditory Displays in Heavy Vehicles

Introduction

Chapter 7 provided design guidance for auditory displays; this topic provides an overview of additional factors that should be considered for selecting the type of auditory display for heavy-vehicle applications. Certain auditory displays may be more appropriate for certain commercial vehicle environments. Although the topics in Chapter 7 are quite generalizable to the heavy-vehicle environment, and may be used for determining interface design features, this topic discusses issues specific to heavy vehicles.

Design Goal: Select auditory display characteristics that accommodate the heavy-vehicle environment and task constraints.
Design Guidance
The literature suggests that these topics and considerations may support the design goal: When selecting and designing auditory displays in the heavy-vehicle environment that will present safety information, there are no known or obvious revisions for the design goals or Design Guidance presented in the following Chapter 7 topics. • Distinctiveness of Warning Messages (page 7-10) • Presenting Warnings Using Speech Messages (page 7-14) • Perceived Urgency of Auditory Warnings (page 7-4) • Perceived Annoyance of Auditory Warnings (page 7-6) • Loudness of Auditory Warning Signals (page 7-8) The Design Guidance statements on 7-2 and 7-12 require revisions for heavy trucking, as discussed below: • Auditory Display Type (see also page 7-2) – Avoid using auditory icons (e.g., tire skidding and loud horn honking) in transit buses. – The use of automotive auditory signals (e.g., simple tones and earcons) is appropriate in heavy vehicles. – At night, auditory displays may be preferable to visual displays in transit buses to prevent drivers from being exposed to glare from the visual display. • Using Localization Cues to Indicate Direction (see also page 7-12) – Spatial auditory warnings may be difficult for drivers to localize in the noisy, acoustic reflective environment of a heavy-vehicle cab. Localization cues, however, may increase the perceived urgency of auditory signals. Some evidence suggests that localized sound may evoke a greater sense of urgency, even if drivers are not able to identify the location of the warning signal due to noise and reflections in the cab [7].

Discussion

Existing evidence supports the use of auditory signals for ICWs to ensure timely perception of warnings in heavy vehicles. However, the nature of an auditory warning must take into account high levels of ambient noise with wide fluctuations in intensity for all large vehicles [1], and warnings in transit buses should be salient enough to evoke correct driver responses [2]. Also, because drivers spend a large proportion of their time in the cab, they are likely to be exposed regularly to CWS sounds, and auditory alerts can be annoying. Consequently, the problems associated with false and nuisance alarms, frequent alerts, and warning signal intensity are highly relevant issues in heavy-vehicle environments. Heavy-truck drivers, however, will be likely to tolerate some level of annoyance with auditory warnings if they see clear safety benefits from using the CWS [3].

Laboratory and limited test-track research have found auditory icons for forward collision warnings to elicit faster brake responses than conventional, urgent-sounding, auditory warnings in heavy truck applications [4, 5]. Auditory icons should be clearly distinctive from other sounds in the cab, with frequency and/or temporal characteristics that are discriminable from other sounds, such as the engine [5]. Reinach and Everson [6] indicate that transit bus drivers often tune out auditory alerts as a method of coping with the noise in the cab. Consequently, it is recommended that auditory icons be used with caution or avoided altogether in transit bus applications.

In the heavy truck environment, the auditory cues that humans use to localize sound are likely to become blurred because of acoustic reflections and noise in the cab, resulting in the potential for diminished ability to identify the location of auditory signals. Nevertheless, recent research has shown that some localized sounds can have greater effect on perceived urgency and situational awareness than comparable omnidirectional signals. In a heavy truck simulator experiment, Larsson et al. [7] demonstrated that 3D auditory signals in a lateral (e.g., lane change) warning were more activating and more negatively valent (i.e., more urgent) than when presented monophonically, even if drivers couldn't identify the direction of the sound. Similarly, in a test track study [5], sounds from the left and right rear speakers elicited slower responses than sounds from the left and right front speakers.

Design Issues

The noisy environment inside heavy-vehicle cabs presents a real challenge to designing auditory displays. The recommended sound levels for auditory warnings may be a problem because ambient noise levels can peak as high as 87 to 97 dBA [1] during discrete periods such accelerating and changing driving gears. The overall duration of exposure in a heavy truck has been shown to be acceptable. For instance, time weighted average (TWA) sound levels can be relatively lower than the Occupational Safety and Health Administration (OSHA) standard of 90dBA TWA for heavy trucks (e.g., OHSA 8 hour TWA of 30 dBA [1]). Note that Hours of Service (HOS) regulations provide property-carrying drivers with driving limits of 11 hours with a 14 hour limit in a duty period, and passenger-carrying drivers with a driving limit of 10 hours with a 15 hour duty period [8].

Temporary muting of other auditory signals (e.g., the radio) during warning presentation can reduce the ambient sound level in the cab. A study of a heavy truck forward collision warning system identified that muting competing audio sources during presentation of an earcon-type auditory alert was not associated with faster brake response as compared to other alerting strategies, yet was identified by participants as making the alert more salient [9].

Cross References

Chapter 7

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Design Guidance for Haptic Displays in Heavy Vehicles

Introduction

Chapter 8 provided design guidance for haptic displays; this topic provides an overview of additional factors that should be considered for selecting the type of haptic display for a heavy-vehicle application. Certain haptic displays may be more appropriate for certain commercial vehicle environments and in general haptic displays may be more accepted by operators (e.g., bus drivers prefer haptic compared to auditory displays [1]). The topics included in Chapter 8 are quite generalizable to the heavy-vehicle environment, and should be used for determining interface design features, like vibration intensity, and where to position vibrating surfaces.

Design Goal: Select haptic display characteristics that accommodate heavy-vehicle environment and task constraints.

Design Guidance

The best available research on this topic suggests that this design goal can be met when the following information is applied in the heavy-vehicle cab:

- Selecting a haptic display for heavy vehicles (see also page 8-2).
  - **Use a *haptic seat* display, unless the use-case for a different display type is very strong:** Commercial driving collision avoidance systems have employed haptic seat, accelerator pedal and steering wheel displays [1, 2] but the haptic seat displays are likely to be better received by most operators.
  - Avoid using a brake pulse display until more research on human factors and information on mechanical issues become available. Brake pulse displays will require additional research for commercial vehicles for the following reasons:
    - The brake pressure required to cause the jerking sensation reported as beneficial for passenger vehicle brake pulse displays may vary as a function of the load carried by the commercial vehicle, heavier loads may require more brake pressure to create the jerking sensation.
    - The implementation of the brake pulse for a heavy truck will be dependent on the trailer type and configuration, load weight, and load distribution.
    - It is highly likely that brake pulse displays are not appropriate for transit buses. Buses are driven as smoothly as possible and ride smoothness is a quality of service factor that is recorded and used for contract negotiations [3].
- General characteristics for haptic displays (see also page 8-4).
  - **Avoid *active haptic interfaces***: These interfaces may be too disruptive, distracting or confusing; research on the human factors aspects of active haptic interfaces for commercial vehicles is limited.
  - **Avoid *steering wheel torques***: Bus drivers have reported a belief that steering wheel torques compromise their control over the vehicle [1]. Although override forces (e.g., 3 ft-lbs; [4]) are low enough to mitigate this concern, consideration may be needed prior to implementing a steering torque display.
  - **Use *passive haptic interfaces*** (e.g., tactile vibrations in the seat): This type of interface offers an opportunity to deliver information to bus drivers that passengers are not able to observe.

There are no known or obvious caveats for the remaining design goals or Design Guidance presented in Chapter 8:

- Improving distinctiveness of haptic displays (page 8-6)
- Accommodating for vibrotactile sensitivity across the body (page 8-8)
- Generating a detectable signal in a vibrotactile seat (page 8-10)
- Presenting spatial information using a vibrotactile seat (page 8-12)

Discussion

Although the research on the use of haptic displays for heavy-vehicle applications is sparse, their use is still recommended. ISO 17361 [5] and Houser et al. [6] state that an LDW system for heavy vehicles should issue a warning via an audible or a tactile display when the warning threshold is exceeded.

There are only a few adjustments to the design information provided in the earlier topics within Chapter 8, and these are simply to avoid the use of brake pulse displays and active haptic interfaces for commercial vehicle applications. The advice against using brake pulses for commercial vehicles is supported by the logic that a high degree of brake force will be required to create the jerking sensation but there is no research to support this claim. The jerking sensation has been reported as the most effective aspect for passenger vehicle applications. For bus applications, the jerking sensation may be problematic as customer satisfaction may be linked with the smoothness of the ride, which would disqualify the general use of brake pulses—there is very little research on this topic as well. We could only find one study to support the claim about the link between ride smoothness and customer satisfaction [3] and it is only moderately helpful. It remains unclear how a brake-pulse display that exclusively activates in an emergency situation impacts bus operations in general. If a break pulse results in drivers stopping buses before catastrophe (e.g., a collision with a pedestrian) such a display may be found quite beneficial.

There are data on the effects of vehicle cab (i.e., whole body) vibrations on driver health and well-being from the occupational health domain/literature, but information like this does not map directly to the design of information systems that use localized vibration to deliver messages. The effects of long term exposure to vibration [7] are not entirely relevant but may provide insight into what vibrational frequencies correspond with typical operations, which is relevant for creating a vibrational signal that contrasts "natural" vibrations but is not adequately documented (see also page 8-6). It is unlikely that the truck models are uniform enough in design for there to be a well-defined model of the vibrations that actually reach the driver [8]. The hardware used to dampen vibration is too diverse to list in any specific manner but—at a high level—tires, suspension, the driver-seat suspension (including active vibration- and shock-mitigation technologies), and engine mounts all dampen vibration.

Design Issues

The design issues mentioned throughout Chapter 8 are applicable to heavy vehicles. In regard to training for passive haptic displays, there is likely a better opportunity in the heavy-vehicle domain to provide drivers with such training as there are already established means to provide training to new drivers [9] and experienced drivers [10].

Cross References

Chapter 8

Topic References

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Driver Controls for Collision Warning Systems in Heavy Vehicles

Introduction

This topic provides design guidance for implementing controls for CWS in heavy-vehicle applications. Specifically, this topic identifies five CWS functions that might be placed under the driver's control. These functions have been identified primarily in passenger car CWS research and design guideline documents, as well as in a limited number of documents that directly addressed heavy-vehicle CWS driver controls. It is readily evident that there is a significant gap in available research upon which to base design guidance corresponding to this topic.

Design Goal: Provide adjustable CWS sensitivity and warning signal intensities to reduce the occurrence of false and nuisance alarms, optimize signal intensity, and reduce driver annoyance.

Design Guidance

The best available research in both heavy- and passenger-vehicles, as well as established human factors concepts when research findings are not available, suggest the following design guidance:

- Avoid allowing heavy-vehicle drivers to permanently disable the CWS.
- Provide controls to mitigate false and nuisance alarms:
  - Provide heavy-vehicle drivers with the capability to temporarily reduce CWS sensitivity or mute auditory warning signals in highly cluttered settings (e.g., construction zones) where high frequencies of false and nuisance alarms would be encountered.
  - Consider using intelligent sensing and algorithms or automated/adaptive techniques for identifying potential false and nuisance alarms in order to minimize the need for drivers to make sensitivity adjustments.
- Provide heavy-vehicle drivers with control of CWS warning visual brightness and auditory volume. Limit adjustments to ensure these signals meet the recommendations for minimum and maximum intensity.
- Consider providing adaptive level adjustment to automatically adjust brightness and/or auditory intensity.

Heavy Vehicle CWS functions: Recommended use and control types.

CWS Function	Recommendation	Use Discrete Control	Use Continuous Control
On/Off Enables and disables the CWS. *Note:* Drivers should be notified of system status for automatic system startup (i.e., ignition activated systems).	Not Recommended	Yes	Not Applicable
Sensitivity (Warning Timing, Warning Threshold, Range, TTC) Controls the physical or temporal proximity threshold for which warnings are activated.	Neutral Recommendation (i.e., can use if desired). Limited Range of Settings[1]	Yes Between 2 and 6 Sensitivity Settings	Yes Precise Adjustment
Master Intensity Master control for intensity of all displays within a modality (i.e., visual, auditory, or haptic). May include non-warning displays (e.g., instrument panel (IP) brightness).	Recommended Limited Range of Settings[2]	Yes Multi-position	Yes Limited Range
Auditory Intensity Controls the intensity of the auditory warning signals.	Recommended Limited Range of Settings[2]	Yes Multi-position	Yes Limited Range
Visual Luminance Controls the intensity of the visual warning signals.	Recommended Limited Range of Settings[2]	Yes Multi-position	Yes Limited Range

[1] Sensitivity adjustment should be limited to prevent drivers from adjusting the system to less than the minimum safe headway or TTC.

[2] Warning signal intensity adjustments should be limited to ensure these signals meet the recommendations for minimum and maximum intensity. See Display Glare, 6-14; and Loudness of Auditory Signals, 7-8 for these recommendations.

Discussion

Most passenger vehicle CWS currently on the market allow drivers to disable the system. Some current heavy truck CWS designs incorporate an on/off control while other configurations do not allow drivers to disable the system. The recommendation in the above design guidance is that a system on/off function not be provided because allowing the driver to disable the CWS would nullify the fleet owner/operator's intent in installing the system. Also, there is some limited research that suggests most drivers would not choose to disable the system if given the opportunity. Specifically, 15 out of 18 drivers in Sayer et al. [1] indicated they preferred driving a truck with an integrated CWS installed, which suggests they would use the technology if available.

System sensitivity settings are commonly implemented in CWS DVI designs. UC PATH and CMURI [2] suggested that system sensitivity should be reduced during driving in a relatively cluttered environment, thereby reducing the frequency of nuisance alarms. On the other hand, Wheeler et al. [3] noted that sensitivity controls may provide the benefit of increased heavy-vehicle operator acceptance at the cost of delaying alerts until insufficient time is available to respond to an imminent hazard.

In a heavy-vehicle FOT [4] that included a lane departure warning system, drivers frequently expressed annoyance with the audible alarm of that system, which was considered to be set too loud and could not be adjusted by drivers. A heavy truck ICW-only FCW presented at 87 dBA was rated as appropriate by approximately 81 percent of drivers, and not loud enough by approximately 15 percent [5]. As is the case with system sensitivity settings, the necessary research has not been conducted to support an evaluation of providing intensity controls on heavy vehicles; although, Houser et al. [6] provides an optional design recommendation of providing an audible warning control with a minimum setting of 65 dBA.

Design Issues

In the absence of available research findings, the present design guidance recommends that heavy-vehicle system sensitivity could be temporarily reduced by drivers to mitigate false or nuisance alarms. The suggested approach is to limit both the duration and frequency of sensitivity reduction, basing the standard sensitivity setting on empirical analysis of driver response times and vehicle stopping distances. In the IVBSS FOT [1], it was suggested that automated tracking could be used to identify locations that produce repeated alerts with the aim of reducing warning sensitivity thresholds to minimize false alerts.

A few references provided information that suggested the potential value of having minimum intensity levels that were dependent upon ambient noise or luminance levels. Reinach and Everson [7] suggested using signal-to-noise difference to create an adaptive minimum audible warning intensity that is at least louder than the ambient noise. Insufficient warning visual luminance in high luminance conditions was identified by some of the transit bus drivers who participated in the pilot test of the integrated CWS reported in UC PATH and CMURI [2], whereas the need for adequately low luminance for night time transit bus operations has been identified by other investigators [7]. These extremes could be accommodated by a system that provides ambient luminance sensing and adaptive display luminance adjustment that considers both minimum and maximum display luminance ratios for high and low ambient illumination conditions.

Cross References

Driver Inputs, Ch. 9; False and Nuisance Warnings, 4-2; Loudness of Auditory Signals, 7-8; Display Glare, 6-14

Topic References

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General DVI Considerations for Heavy Vehicles

Introduction

General DVI considerations are tied to situational factors and other operating demands heavy-vehicle drivers regularly experience. While the design goals and design guidance presented in Chapter 3 are generally applicable to heavy vehicles, the information below provides some additional considerations specific to heavy vehicles.

Design Goal: Design DVIs with careful consideration of the existing demands imposed by the heavy-vehicle driving task so as to avoid disruption or interference with driving performance.

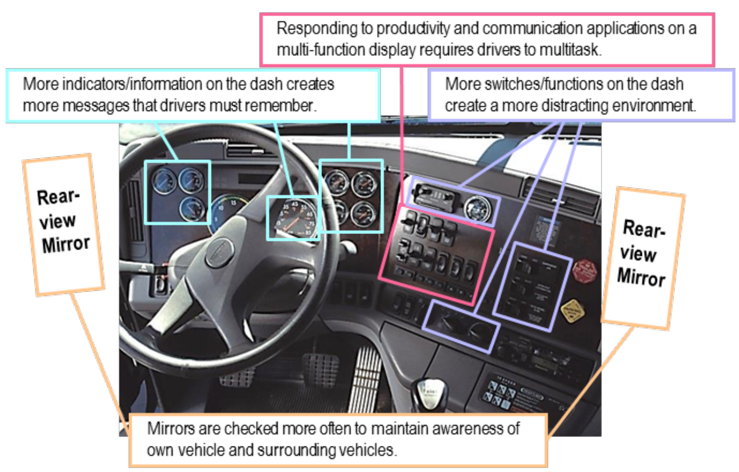
Design Guidance

The best available research suggests the following key features and design implications may affect this design goal:

Heavy Vehicle Drivers…	Design Implications
…face greater workload under normal driving conditions.	Due to vehicle size and loading, a manual transmission, significant mirror use, and a greater need to be aware of their vehicle position in relation to other vehicles, heavy-vehicle drivers typically encounter higher levels of workload than light vehicle drivers [1].
…continually deal with secondary task demands.	Because there are secondary tasks the driver is required to perform (e.g., route monitoring, road restrictions, using dispatching/routing systems) in addition to the primary task of driving, heavy-vehicle drivers must multitask while driving [1, 2].
…face a greater number of in-cab messages that require attention and memory.	More indicators on the dash, the result of a more complex cab environment, create more messages that heavy-vehicle drivers must remember [1].
…benefit from effective training.	Heavy vehicle drivers have more tasks they must learn how to perform and information they need to deal with, and they benefit from enhanced training. [3, 4]

When developing a safety system or application, research suggests minimizing the degree to which the application or the information it provides adds to the complexity and workload of operating the heavy vehicle. Such added complexity and workload could have negative consequences on driver performance. New systems and information should be integrated into the cab environment with due consideration of workload and performance concerns. Use non-invasive messages to provide non-safety related information, and take into account the driver's ability to perceive and respond to messages while driving. Chapter 10 provides additional information.

Common sources of workload and distraction in the heavy-vehicle cab environment.



Photograph: Comstock/Getty Images. Used with permission.

Discussion

Distraction: The presence of certain driver systems in a heavy-vehicle cab may create a more distracting driving environment than that of passenger vehicles. For instance, many heavy-vehicle drivers are required to interact with dispatching devices that provide route, load, and other communications with the office; these systems have the potential to have high levels of driver distraction [2]. When designing a DVI for use in a heavy-vehicle cab, the DVI should not add to the complexity of the driving environment. This can be accomplished by minimizing the use of attention getting methods such as a flashing icon in a non-urgent situation, locking-out certain functions of the DVI while the vehicle is in motion, or by presenting information to the driver using a modality that does not compete with those used for the driving task (e.g., auditory versus visual or verbal versus spatial) [5].

Workload: The workload that heavy-vehicle drivers encounter under normal driving conditions is greater than for passenger vehicle drivers due to the nature of the driving task and due to the overall higher level of awareness required regarding their own vehicle and surrounding vehicles. Heavy vehicle drivers are often trained using structured systems (e.g., the Smith System [6]) which intend to help drivers anticipate, see, and react quickly to driving challenges unique to heavy vehicles [3]. New DVIs or applications should not interfere with tasks or activities that drivers are trained to complete via their training program.

Secondary Task Demands: While heavy-vehicle drivers have secondary tasks they must perform in addition to the primary driving task, they must multitask to accomplish all of the required tasks. For example, drivers may have a route and schedule they must stay on, are required to visit weigh stations as necessary, and the majority of drivers have the same tasks of maintaining a trip log, tracking tolls they pay, and tracking the amount of time they spend in a state, etc. [1]. To enable drivers to perform these tasks in addition to the primary driving task (only as necessary), the tasks should be self-paced and use continuous displays so that drivers can access and use the information at a time of their choosing.

In-cab Messages: Heavy vehicles have a number of systems or features that are not found in light vehicles (e.g., turnable axles, air systems, leveling systems, truck diagnostics displays) [1], resulting in more indicators on the dash. This in turn creates more messages that heavy-vehicle drivers must remember. One way that this information can be communicated to the driver is by using an icon, text or other visual display, which is covered in *Visual Display Type for Safety-related Messages* (page 6-2). If another type of display is more appropriate, it should be presented in a simple form, with a low number of information units, resulting in low memory demands on the driver. Information on this topic can be found in Chapter 5 *Message Characteristics*.

Training: Heavy vehicle drivers benefit from effective training on the various tasks they are required to perform in their vehicles because of the differences in operating a heavy vehicle compared to a light vehicle. When properly trained, drivers are able to operate their vehicle more safely and are able to react to unexpected situations with more ease than inexperienced drivers. It should be noted, however, that the amount of training and the type of training received can vary greatly among heavy-vehicle drivers. A study by Morgan, Tidwell, Medina, and Blanco [4] examined the effectiveness of three different types of training on commercial motor vehicle drivers' skill levels and found that longer, more structured training can offer distinct benefits that may increase operational safety on public roads.

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Chapter 12. Tutorials

This chapter contains informational tutorials. Tutorials are provided for important topics, special issues, and detailed procedures that cannot be addressed within the two-page constraints of individual design guidance topics.

Tutorials included in this chapter:

- Tutorial 1: Procedures for Assessing Driver Performance: Visual Demand Measurements
- Tutorial 2: Priority Order Index Look-Up Table for Message Prioritization
- Tutorial 3: Preliminary HFCV Integration Architecture
- Tutorial 4: Heavy Vehicle Characteristics and Driving Environment Relevant to DVI Design

Tutorial 1: Procedures for Assessing Driver Performance: Visual Demand Measurements

Introduction

Assessments of DVIs could include obtaining qualitative opinions about the system, examining driver performance with the system, measuring the visual demands associated with the system (the specific focus of this tutorial), and/or by assessing broader constructs such as workload or distraction. Such assessments could occur at any point during design. Assessments of early prototype interfaces could provide valuable insights for later design stages.

The goal of this tutorial is to provide an overview of methods and procedures for assessing visual demand, and to list specific data sources that can provide more detailed information for interested readers. The tutorial begins with discussion on a set of general heuristics for selecting assessment methods. These heuristics are broadly applicable and are included early on to provide readers with methods to evaluate the visual demand assessments discussed throughout the remainder of the tutorial.

The majority of the tutorial consists of descriptions of methods and required minimum instrumentation for carrying out assessments of visual demand. It also discusses selected study examples that provide basic assistance relevant to using the assessment or research methods. For the needs of this tutorial, visual demand should be considered as the proportion of time that a driver's eyes are directed toward a task, primary task of driving or secondary tasks. The amount of time that a driver's eyes are on the road scene has been used to empirically study attentional and visual demands of driving (e.g., Senders et al., 1967; Tsimoni et al., 1999). For assessments of in-vehicle system with interaction interfaces for the driver, visual demand has been assessed using the amount of time that the driver or user looks at the interface (e.g., Horberry et al., 2008; Angell et al., 2006).

The tutorial is designed to be read chronologically; it is organized as follows:

- Heuristics on Selecting a Driver Performance Assessment Procedure
- Descriptions of Selected Visual Assessment Techniques

Heuristics on Selecting a Driver Performance Assessment

While selecting a method for assessing driver performance, there are some heuristics that readers should consider:

- **A selected procedure should satisfy the "needs" of the assessment**. In order for practitioners to be able to select a procedure (or set of procedures), they need to determine if it fulfills their assessment/research goals, as well as any schedule limitations and budget constraints. Details about how driver performance studies have been carried out will help when determining if a procedure is appropriate.
- **Knowing the origins of a potential measure can be useful**. Often it is the case that in order to fully realize the implications of a procedure, it is necessary to have an understanding of its rationale. As a result of the different ways in which seemingly-similar procedures are actually carried out, it can be unclear as to what practitioners are attempting to measure or accomplish. In some cases, it is necessary to review additional sources, including those that describe the original purpose of a specific procedure.

- **Ensure the assessment procedure is a valid measure of the construct of interest**. Some tasks are more strongly associated with visual demand (e.g., radio tuning), others involve primarily cognitive demand (e.g., mobile phone conversation), and some tasks can include both visual and cognitive demand components (e.g., manual phone number dialing). Understanding how these demands impact driving behavior (e.g., lane exceedances) is critical; it is important to use appropriate methods to evaluate visual and cognitive load on the driver and to be aware that there are many driving tasks that occupy both constructs of demand (see Figure 12-1 below).
- **Assess the components of the system that the driver will experience**. It is important to consider the purpose of assessments of driver performance within the larger context of system design. Assessing the visual demands of an in-vehicle device includes examining those aspects of the system that drivers actually experience (e.g., interface designs, activation parameters, etc.) and—specifically—how well the driver interfaces support the functional goals of the system, and the extent it does so in a way that maintains safe driving.

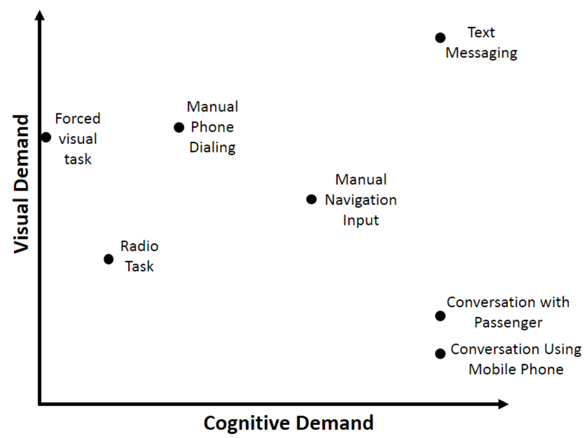


Figure 12-1. Visual and cognitive demands of common in-vehicle tasks (Adapted from Engstroem & Maard, 2007).

- **A key purpose for assessing the visual demand associated with a system is to approximate how design features influence when and for how long drivers look at the DVI and away from the road**. Crash risk increases by three to four times that of normal driving when drivers are visually distracted (Dingus et al., 2006; and Neale et al., 2005). Not all glances away from the road carry the same degree of risk. Shorter glances away from the forward roadway have been shown to have very little influence on crash risk, longer glances (e.g., greater than 2 seconds for any purpose) increase crash risk by twice that of normal driving (Klauer et al., 2006). A key determinant of visual distraction is where the driver is looking and for how long. The safety effects of an in-vehicle device depend on an ability to reliably determine the visual demand associated with the device—i.e. how the system affects the duration and location of where drivers look. This tutorial contains a review of assessment techniques that have been used to evaluate visual demand issues associated with driver support systems. There are a limited number of techniques available to assess visual demand issues associated with collision avoidance systems. Although there may be an opportunity to adapt many of the evaluation practices and research procedures that are used to assess other types of information systems (e.g., in-vehicle navigation systems), this option has yet to be fully explored. Accordingly, assessment methods for collision avoidance systems will certainly need to be further developed before standardized practices are possible.

It is important to note that novel assessments techniques will be needed. It is highly likely that there may not be an assessment procedure available for a specific research or assessment need. Even the most mature collision avoidance systems (e.g., FCW and LCDAS) lack adequate assessment techniques. Although there is considerable literature on these systems, there is also considerable inconsistency in both the research and assessment procedures.

Descriptions of Selected Visual Demand Assessment Techniques

Table 12-1 below lists common assessment techniques, indicates which techniques have standards or best practices documentation available, and which area of demand (visual, cognitive, or both) they assess. There is an enormous amount of literature on the listed techniques, as well as many other techniques that are used less often. There have also been multiple workshops on driver metrics. Two of the four workshops occurred at Driving Assessment conferences. Proceedings papers from the 4th workshop were published as a book that contains papers by many practitioners in the field and is a recommended text for those interested in the research aspects of driving metrics (Rupp (Ed.), 2010; see especially Angell (a, b), Benedict & Angell, Burns et al., Engstroem, McGehee et al., and Perez et al., which are included with other sources in an Additional References section at the end of the tutorial).

Table 12-1. Common assessment techniques.

Common Assessment Techniques (*tutorial topic*)	Standardized	Type of Demand
Eye Glance Measures - Video Methods	Yes	Visual
Eye Glance Measures - Eye-Tracking Methods	No	Visual
Visual Occlusion Method	Yes	Visual & Cognitive
Occlusion Methods for Driver Assistance Systems	No	Visual & Cognitive
Peripheral Detection Task (PDT) *ǂ	In consideration	Visual & Cognitive
Lane Change Test (LCT) *	Yes	Visual & Cognitive
Sternberg Proxy Task **	No	Cognitive

* These are techniques for assessing cognitive demand, but because of the use of visual stimuli these techniques are often conflated with visual demand; resolving the similarities between these techniques is a topic that is outside the scope of this tutorial.

ǂ See Hsieh, Young and Seaman (2012) for details on the development of a PDT standard.

** The Sternberg Proxy Task is a widely-used assessment technique, so we have listed it here; however, it is not a visual demand assessment technique and is, therefore, not described in this tutorial.

The following sections discuss how visual demand has been assessed using direct measures of visual behavior (e.g., measurements of eye movements) and techniques that block-out vision for short durations (e.g., visual occlusion methods). Eye glance measurements are discussed in the context of standards and best practices (e.g., ISO and SAE standards and best practices documents). Similarly, a later section on the visual occlusion method discusses standards and best practices. Also discussed are alternative occlusion techniques that are not current standards and best practices but have a long history of use for researching the effects of certain systems on driver behavior. These alternative non-standard techniques may be more appropriate for assessments of collision avoidance systems. The standard assessments are less suitable for most collision systems due to their specific focus on completing longer duration tasks that are secondary to driving.

Direct Measurement of Eye Glance Behavior

Measuring eye glance behavior can provide information on where drivers look (e.g., toward the roadway or toward in-vehicle devices). This section describes some basic aspects of eye glance measures. Discussion on video-based and eye-tracker based methods follow.

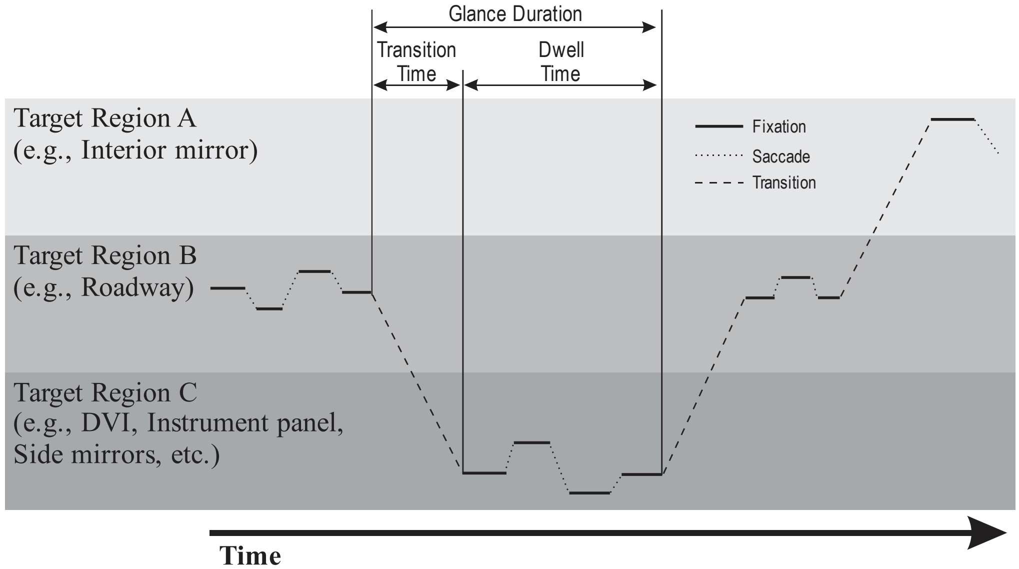
Quantifying where drivers are looking can help to identify how much visual demand is imposed by in-vehicle systems and the driving environment. Driver's visual search strategies can be influenced by the visual demand of both the road scene and visual elements within their vehicle. Informational needs of a driver contribute to visual search strategy (Hughes & Cole, 1988), but informational needs change and depend on the intentions and expectations held by the driver; this is in addition to the attention-capturing nature of the visual elements in the vehicle or in the driving scene also influencing where drivers look (e.g., Cole & Hughes, 1984). Although drivers tend to look toward what is relevant in the driving environment (e.g., toward the roadway or focus of expansion), not all drivers exhibit the same glance behavior. Experienced drivers are better at looking toward relevant elements of the driving environment than inexperienced drivers (Falkmer & Gregerson 2005). There are also instances when drivers look away from the road for durations that can undermine safe driving (e.g., when glances are longer than 2 seconds; Klauer, Dingus, Neale, Sudweeks & Ramsey, 2006). Since eye glance behavior can be collected using video-recording or eye-tracking systems, researchers and designers can obtain decent estimates about how systems affect where drivers look.

General Information and Terminology

Some definitions are needed before moving on. For the remainder of this section, it will be important to understand what is meant by *target, fixation, saccades, glance,* and *transition* as these basic measures are highly relevant to additional measures discussed later. These basic measures are defined in Table 12-2 below and can be obtained using video or eye-tracking methods, as discussed in this tutorial.

Table 12-2. Basic eye movement measures and definitions.

Basic Eye Movement Measures



- **Target:** A target is a predetermined area within the visual scene (e.g., road, mirrors, in-vehicle displays, controls, IP devices, or combinations like Target Region C shown above). When video-based methods are used there should be a minimum separation distance of at least 20° between targets. This will facilitate differentiating between glances at different targets.
- **Fixation:** Fixation occurs when the eyes are aligned so that the fixated target or area of interest falls on the fovea (central point of vision) for a given period of time (100ms to 20000ms; ISO 15007-1:2014).
- **Saccade:** The eye-movement that leads up to any fixation within a target region.
- **Transition:** The eye-movement from a fixation, glance location or one defined target location to another target location (e.g., glancing from the road scene to an in-vehicle display; SAE J2396).
- **Dwell Time:** The total fixations and saccades within the target area between transitions (SAE J2396).
- **Glance:** The time from the moment at which the direction of gaze moves toward a target (e.g., an eye movement toward the interior mirror) to the moment it moves away from target, i.e., this includes the transition time to that target and dwell time (SAE J2396).
  Glance is the most important metric as it is used to derive multiple other metrics.

The SAE recommended practice for measures of driver visual behavior, with respect to visual targets that do not change their location over time (e.g., side mirrors) and for drivers that remain reasonably still, provides definitions of various measures that can be obtained using video methods (SAE J2396, 2000). Additionally, many of the measures can also be obtained using eye-tracking methods since eye tracking methods are more general and can be used for visual targets that change location over time and with drivers that vary their position. Assuming the above conditions are met, one key factor for determining whether or not to use a video or eye-tracking method is the granularity or size of the visual targets that are part of the evaluation. Video methods can be used when the targets of interest are large and lead to eye movements that cover more distance (e.g., the roadway as one target, another target being the interior mirror; Smith, Change, Glassco, Foley, & Cohen, 2005), but video methods are less practical for looking at finer grain eye movements between smaller areas of interest (e.g., areas of interest within the forward view; Caird, Chisholm, & Lockhart, 2008); this is where eye-tracking methods become more necessary.

Table 12-3 contains recommended measures, additional measures used in research, and measures used in practice for evaluations of in-vehicle systems.

Table 12-3. Additional eye glance measures and definitions.

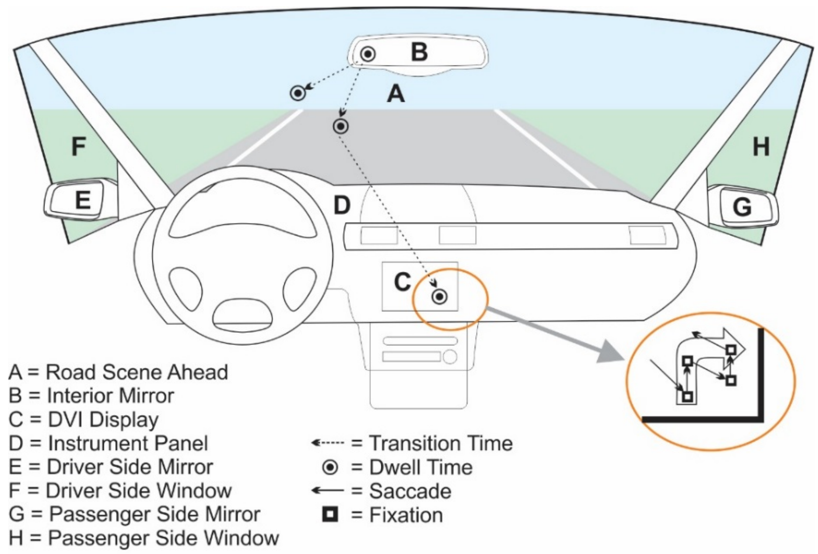
Additional Eye Glance Measures and Definitions
• **Dwell Time:** The sum of the duration of all glances/fixations and other eye movements (e.g., saccades) within a defined area that contains the visual target (SAE J2396). • **Glance Frequency:** The number of glances to a target within a pre-defined sample time period, or during a pre-defined task. Each glance must be separated by at least a single glance to a different target (SAE J2396). • **Glance Probability:** A ratio of the sum of all transitions to a specified location divided by the sum of all transitions between all pairs of locations that occurred during the sample interval. This measure reflects the proportion of transitions to the specific location of interest (SAE J2396). • **Link Value Probability:** The probability of a glance transition between two different locations. For example, the link value probability between target locations A and B is defined as the number of glance transitions from A to B plus the number of glance transitions from B to A; this sum divided by the total number of glance transitions between all pairs of locations in the sample interval is the link value probability (SAE J2396). • **Time Off Road Scene:** The total time for glances away from the road scene (SAE J2396). • **Transition Time:** The duration between the end of the fixation on a target location and the start of the fixation on another target location (SAE J2396). • **Time-to-initial-transition:** The amount of time between the onset of a visual element in the driver's field of view (e.g., a visual alert) and the last glance from an area of interest (e.g., a display with a distraction task; Perez et al., 2009). • **Gaze Variability:** Standard deviation in eye positions during a test interval. Vertical and horizontal variability can be reported as separate measures (Caird et al., 2008). This measure will require an eye tracker.

Glance data can be compared to other objective measures such as lane position variations, counts of lane boundary crossings, lane departure duration, and speed variability. When reaction times (e.g., accelerator-release reaction time, brake press time, button-press time) are included and coupled with eye glance information, variables like *forward glance decision time* can be derived. Forward glance decision time is the time between when a forward glance initiates and the desired response occurs (Perez et al., 2009).

Table 12-4 shows a diagram of visual locations. The visual locations can serve as either individual targets or multiple visual locations, both of which can be combined to create larger target regions. The extent to which the visual locations are combined will depend on the technique that is used to measure eye movements, video- or eye-tracker methods.

To a certain extent, eye-trackers can be used to obtain information at the level of the visual location. Information about head rotational position will be necessary if practitioners are to use the coordinate values from the eye tracker to compute a gaze vector or point of regard. There are systems available to track eye and head movement (e.g., EYEHEAD by ASL, faceLAB by Seeing Machines). It will not be possible to compute the point of regard for other areas of interest without head position information, unless the scene plane is known (e.g., as is the case with eye trackers that are affixed to a display). The actual head movements that occur while driving make computations of gaze appreciably more complex.

Table 12-4. Diagram of visual examples.

Examples of Visual Targets

This excerpt is adapted from ISO 15007-1:2014, Figure A.1 on page 5, with the permission of ANSI on behalf of ISO. (c) ISO 2014 - All rights reserved
• **Video methods are useful for coarser targets:** e.g., the road scene as one target (A), another target could be a combination of finer targets identified as a target area, for instance in-vehicle or off-road (B, C and D, E and F, G and H). • **Eye-tracking methods are useful for finer targets:** e.g., determining precisely where the driver is looking within a DVI (C), the vehicle (B, C, D, G, E, etc. independently) or the road scene (areas of interest within A).

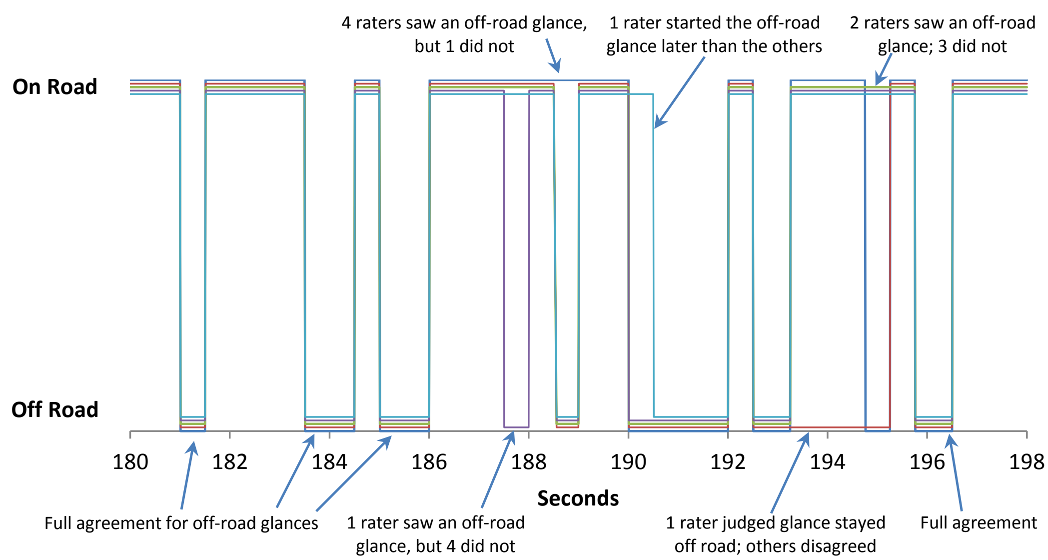
Video Methods

Video methods can be used to obtain useful information about driver visual behavior. Video that is captured during naturalistic studies can be examined to identify where drivers were looking during pre-crash scenarios, which might provide insight on driver inattention (e.g., Klauer et al., 2006). Many researchers have used video methods to observe driver visual behavior. Smith et al. (2005), Angell et al. (2006) and SAE J2396 provide comprehensive reviews of methodological considerations. Accordingly, these were the main resources used for the remainder of this section about using video methods. Data capture and reduction techniques for video based eye movement measures are summarized in Table 12-5.

The Crash Avoidance Metrics Partnership used software to code videos to expedite their data reduction process. The software is called Observer 5.0 and is produced by Noldus Information Technologies. It was used to code video, generate plots, and conduct inter-rater reliability. For details on how this software was used to code video and complete additional analyses see Angell et al., 2006.

Table 12-5. Summary of data capture and reduction for video-based eye movement measures.

Video Method: Data Capture	
Setting up: How to position the cameras (SAE J2396)	• Ensure there is a clear view of the driver's eyes by using proper positioning, aiming, and exposure control of interior video cameras. • Multiple cameras (2+) can be used and placed near the areas of interest and aimed toward the driver to capture their eyes when they look toward the area of interest. • Additional cameras can be used to identify when drivers are looking toward other areas of interest.
Calibration (SAE J2396)	• Calibrate the position of the cameras before data collection begins and at regular intervals during tests (e.g., every 30 minutes). • Calibrations are done to account for changes in driver posture that may affect how well the cameras capture the driver's gaze. • The segments of the video recordings that contain the calibration can assist data coders in deciding the characteristics of the driver's visual behavior.
Video Method Data Reduction (Smith et al., 2005)	
Steps for reducing video data: 1. **Select and define areas of interest:** e.g., on road and off road. 2. **Select raters:** A team of 2 raters with an optional third person to arbitrate disputes between the two raters. Rating teams that are larger may be much less likely to reach consensus. A team of 5 raters was used to reduce the video data to generate the plot below. Notes on which glances were disputed are shown. 3. **Train raters:** To ensure that all raters equally understand how to identify the defined areas of interest, train them as a group rather than independently; if they all have the same understanding they will be better equipped to resolve disputes. 4. **Complete within-frames analysis:** The first step is to have raters independently identify where the driver is looking within each frame of video and mark the frame with the area of interest or target the driver was looking at (e.g., on-road or off-road). 5. **Collate within-frames analysis:** Convert the video frame number to represent a time-stamp that can be used to graphically represent visual behavior or be used to compute inferential statistics; this conversion also allows for generating a correspondence with other data that are collected. Converging data in this manner requires that the video be time synced with the other measures of interest (e.g., combine eye glance data with acceleration data for multivariate analyses).	



Recreated from Smith et al (2005). Methodology for capturing driver eye glance behavior during in-vehicle secondary tasks. Transportation Research Board, No. 1937, Figure 1, p. 64. Copyright, National Academy of Sciences, Washington, D. C., 2005. Reproduced with permission of the Transportation Research Board.

Additional Considerations for Coding Glances From Eye Movement Videos
There are two additional data codes that have been used to categorize eye movements. CAMP used these data codes in their Driver Workload Metrics (DWM) study to further quantify eye movements (Angell et al., 2006). 1. **Task related glances:** This code is used to identify glances that are linked with a non-driving task. The simplest approach is to couple the start and end times of the task to the eye movements. Target regions can also be associated with a task; e.g., CAMP labeled all glances down toward or near the IP and centerstack as task related, but their process did require mediation from a 3rd video coder as sometimes judgments of where drivers were looking was not agreed upon by their main team of raters. 2. **Glances used to track signs and roadway structures:** Drivers may visually track signs or structures for a segment of time leading up until the sign disappears from view, and this is considered a tracking eye movement. Researchers may want to exclude these types of glances from analysis of specific areas of interest.

Eye-Tracking Methods

There are several eye-tracking systems on the market. Eye trackers can be worn on the head (e.g., ASL's The Mobile Eye), incorporated as part of a display or interface (e.g., Tobii X2 Eye Trackers), or mounted on a vehicle dash (e.g., Seeing Machines faceLAB). All these systems use cameras to capture images of infrared light reflected off of the cornea of the eye (i.e., Purkinje images which are reflections of light off the boundaries of the lens and cornea of the eye). The spatial relationship between these reflections and the location of the retina change in a relative way depending on the rotation of the eye; this spatial relationship is used to calculate gaze position, assuming the point of regard is known or included. The set-up, calibration and data reduction process is quite different from using video methods. The data capture process is outlined in Table 12-6 below.

Eye tracking equipment manufacturers typically offer data reduction software. These software programs provide a wide variety of measures that are automatically processed. A few examples of typical measures included in eye tracking software are: gaze paths, fixation heat maps, and dwell time measures. Gaze paths and heat maps are often shown in combination with what the eye tracking wearer was presented (e.g., heat map overlaying an image of a DVI).

Table 12-6. Summary of data capture and reduction using eye-tracking measures.

Eye-Tracking: Data Capture	
Setting up: First step is to position the cameras and infrared light source	• Eye-tracking systems usually consist of two types of cameras: a scene camera and cameras for imaging the eyes. • An infrared light must be incident toward the eye or eyes to create the required reflections. • Set-up typically requires ensuring that the cameras are aimed at the appropriate areas of interest—with head-mounted eye-trackers; this may involve adjusting a reflective monocle to ensure it is correctly lined up with the camera that is capturing the image of the eye.

<table>
<tr><td>Calibrating the eye-tracker (Lange, 2013)</td><td>

Calibration is necessary to ensure that the system calculates the point of fixation correctly.
The calibration process typically requires that the observer focus their gaze at known areas of interest. This can be accomplished using matrices of visible dots that are shown across the field of view. (e.g., matrices of 4, 9, or 16 dots that are spaced apart equally across the field of view).
With many eye trackers, the eye-tracking data can be viewed in real-time as an overlay with the video from the scene camera; this arrangement can be used to verify calibration by requiring the observer to look at a predetermined location while the researcher watches the video overlay.
It is very important to assess for calibration shifts. This should at least be done at the end of the data collection phase. If the calibration has shifted there are two options:

If the point of gaze still appears within adequate proximity to the area of interest the data may still be valuable.
If the shift is too great, the data may need to be discarded and replaced using a different participant.

Depending on the eye-tracking software, recalibration may be possible and advised after a specific time interval (e.g., calibrate every 15 minutes) to reduce data loss due to calibration shift.

</td></tr>
<tr><th colspan="2">Eye-Tracking Data Reduction</th></tr>
<tr><td colspan="2">It is beyond the scope of this document to provide information on the computational aspects of reducing eye-tracker data. Commercial eye-trackers are packaged with “canned” software that computes myriad measures of visual behavior (e.g., those listed in this tutorial, heat-maps, scatter-plots, etc.). Some general recommended texts that discuss methods to reduce eye-tracking data are:

Duchowski, A. (2007). Eye-tracking methodology: Theory and practice (2nd Ed.). London: Springer–Verlag.
Holmquist, K., et al. (2011). Eye-tracking: A comprehensive guide to methods and measures. Oxford: Oxford University Press.

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

Methods of Visual Occlusion

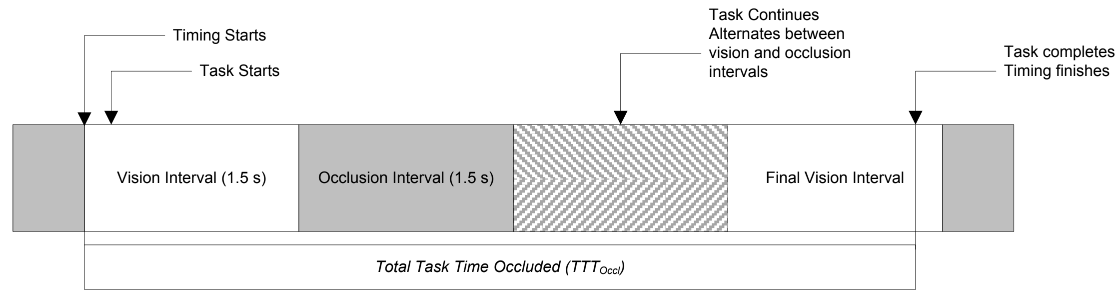
ISO Visual Occlusion Method – The Standardized Proxy Task

The visual occlusion method can be used to assess visual demand associated with the use of visual interfaces (ISO 16673, 2007). The standardized visual occlusion method is considered a proxy for tasks that require drivers to balance their attention between driving and looking away from the road to interact with an in-vehicle device. The results of tests that use the visual occlusion method can be used to determine if an interface is appropriate for the task that it was designed to support. This method can be used during early phases in the design life-cycle, as well as all the way through to later phases. The major benefit to using the occlusion method is that it is simple and can be accomplished with very little investment in specialized equipment. Tools like eye-trackers and video cameras are not necessary. The major drawback is that the standard occlusion method does not apply to assessments of most collision avoidance systems. The standard method is discussed in the next table and limitations are included at the bottom of Table 12-7. Some basic equipment is mentioned, dependent measures are discussed and an illustration of a test trial is provided.

Table 12-7. Summary of data capture and reduction using ISO's visual occlusion method.

Visual Occlusion Method (ISO 16673)	
Standard Methods	The basic method requires that a participant complete a task using an in-vehicle interface. The task should be completed while cycling between blocking and unblocking the participant's view of the in-vehicle interface. These vision and occlusion intervals should be 1.5 seconds each. Cycles between vision and occlusion intervals should occur until the task is completed and the participant verbally indicates that they are "Done!" The amount of time or number of block/unblock intervals it takes for the person to complete the task is recorded and compared to other measured parameters. Some considerations for test methods are: • **Appropriate Test Environments:** The test environment can be the vehicle cockpit if the location of the interface is an important factor, or it can be a computer screen if the interface location is not relevant or not yet relevant. • **Number of Participants:** At least 10 participants should be used. • **Number of Test Trials:** There should be at least 5 test trials per participant. • **Age:** 20 percent of the participants should be over 50 years old. There will surely be an effect attributed only to age. Practitioners should be prepared to look at the data from older drivers independently from younger drivers (Horberry et al., 2008). • **Training:** Two to 5 training trials may be necessary but the actual amount should be based on how quickly the participant learns the task being tested and what is required of them for the occlusion method.
Equipment	• The visual display itself could be blanked out as a possible technique for achieving occlusion, or vision can be blocked completely by using occlusion goggles (e.g., Portable Liquid-Cyrstal Apparatus for Tachistoscopic Occlusion (PLATO) light emittting diode (LED) lenses by Translucent Technologies Inc.). • The purpose of occluding the display is to interrupt the visual portions of the task in a controlled manner. ISO 16673 indicates that participants should be told that they are allowed to operate the controls during the occlusion period. Practitioners allow continued interaction even with displays that lack physical buttons (e.g., touch screen interfaces) that tactually perturb the skin when touched (e.g., Horberry et al., 2008).
Standard Measures	• **Total Task Time in Occluded Conditions (TTT_{Occl}):** This is the total task time for completing the task for trials that contain occlusion intervals. This provides a measure of task duration when the user is experiencing continual interruption. • **Total Task Time in Un-occluded Conditions (TTT_{Unoccl}):** This is the total task time for completing the task for trials that do not contain occlusion intervals. This provides a measure of task duration when the users are not interrupted. • **Total Shutter-open Time (TSOT):** This is the total time that the subject can see the interface while completing the task—i.e., the total time elapsed over only the visual intervals of the trial. • **Resumability Ratio (R):** This is a ratio of TSOT over TTT_{Unoccl}. It provides an indication of whether periodically shifting attention away from the in-vehicle interface results in added time to complete the task. This additional time can be considered as a cost, or an increased demand of performing the task while driving. The value of R should be calculated on a within-participant basis. Logically, values greater than 1 indicate there is an added cost to completing the in-vehicle task while driving, but ISO gives no guidance on specific criterion values for R and they suggest that users establish their own pass/fail criteria. Additional research is required before establishing a standard target criterion value. None of these measures indicate how well the task was performed.

Diagram of a Test Trial under the Occlusion Condition



Limitations to the Standard Process

- **The standard process is not appropriate for assessing tasks that are shorter than 5 seconds.**
  There are not enough shutter open and close intervals during short interval tasks (< 5 seconds) to provide enough information about visual demand (ISO 16673). An alternative timing of 2 seconds for the closed occlusion interval was used in the CAMP DWM project but in these studies the open interval was 1.5 seconds (Angell et al., 2006).
- **Mis-estimations of resumability may result if the standard method is used without including a cognitive task during the occlusion interval.**
  The occlusion interval does not at all impose additional cognitive demand on the participant, as does actual driving. During actual driving the driver can be under various amounts of cognitive demand resulting from glances toward the driving environment. Also, the standard occlusion method does not include a requirement to impose cognitive demand during the occlusion interval. As a result, R may fail to account for additional resumption costs associated with the extent cognitive load of driving also interrupts the task (Monk & Kidd, 2007).
- **System delays can result in idle time that must be subtracted from task time measures.**
  Occlusion methods are not recommended for in-vehicle devices that exhibit system-response delays, however, occlusion methods could provide estimates of effects on visual demand if the delay durations are subtracted TTT and TSOT measures (ISO 16673).
- **Benchmark value for excessive visual demand is not agreed upon and can be chosen by the user of ISO 16673.**
  The standards document for the occlusion method indicates that users develop the benchmark values and criterion for excessive visual demand. The Alliance of Automotive Manufacturers (AutoAlliance) and the Japan Automobile Manufacturers Association provide criteria and benchmarks (see Foley, 2008). AutoAlliance states that TSOT for a task should not exceed 15 s, while JAMA states that it should be 7.5 s. JAMA also suggests a vision interval of 1.5 s and an occlusion interval of 1.0 s.

Occlusion Methods for Driver Assistance Systems – Alternative Assessment Techniques

Researchers have used alternative techniques to assess driver support devices and many of these techniques are similar to the standardized occlusion method only in that vision is blocked for specific intervals during test scenarios. For all intents and purposes, the example methods described in the subsequent table should be considered orthogonal to the standard occlusion method. These alternative techniques have been used to evaluate driver support systems such as heading control systems and collision warning systems. There are many insightful studies like these that methodologically occlude vision in a way that is fundamentally inconsistent with the ISO 16673 Standard Visual occlusion method. The standard occlusion test does not support assessing the visual demand of all driving systems, which generates a necessity for these unique methods, while also illustrating a need to develop a common or standardized method that can be used for assessments of collision avoidance systems. This is not meant to dissuade anyone from using the standard method, the standard occlusion method has been heavily scrutinized and, as a result, the most basic aspects are now thought of as an insightful test of the level of visual demand associated with an interface, but researchers and practitioners need to be aware of its limitations.

This section discusses three visual occlusion techniques that are alternatives from the standard method. The techniques are listed and discussed in the form of a structured literature review of some relevant research (for additional examples see Van der Horst, 2004). Unlike the standard visual occlusion method, these methods are more complex and the results are often more difficult to interpret. The list below is sufficient to demonstrate that occluding a driver's vision allows for multiple approaches. The literature shown in Table 12-8 was chosen to demonstrate three different occlusion methods.

Table 12-8. Literature review of three studies using occlusion methods of visual data capture.

Three Visual Occlusion Methods	
1. Briefly occlude vision while the driver makes a maneuver that is relevant to the function of the system.	
Schumann, J., Godthelp, H., Farber, B., & Wontorra, H. (1993). Breaking up open-look steering control actions—The steering wheel as an active control device. In A. G. Gale et al. (Eds.), *Vision in Vehicles IV*. Amsterdam: Elsevier Science.	• For this study, participants drove on a two-lane road and were required to merge into the left lane. During the lane-merge their field of view became either completely obscured for a fixed occlusion period (e.g., 2.4 seconds) or was left available and un-obscured. These two conditions were repeated for several trials for each person. In many trials a barricade appeared in the left-lane to indicate that the lane was closed, which prompted participants to return to their driving lane. In other trials the barricade was in the right-lane, which reinforced the purpose of the lane merger. For trials with a barricade in the left lane, an alert was activated at a specific distance. There were 3 varieties of alerts based around steering wheel rotational torque, the first one was *weak and continuous*, the second was *weak and discrete*, and the third was *strong and discrete*. • The results showed a large and significant effect supporting the use of the strong + discrete warning type, but only when vision was occluded. When vision was not occluded there was no substantial difference between the various alert styles. If this study had not included the occlusion period then the assessment could have mistakenly concluded that all of the alert types were equally effective, rather than demonstrating the superiority of the strong/discrete warning.
2. Continuously occlude vision but make it available for short intervals at request of the driver.	
De Vos, A. P., Godthelp, J., & Kappler, W. D. (1999). Subjective and objective assessment of manual, supported, and automated vehicle control. In: J. P. Pauwelussen, (Ed.), *Vehicle Performance* (pp. 97-120). Exton, PA: Swets and Zeitlinger, Lisse.	• For this study, drivers' visual field of view was obscured while they were driving and only when they pressed a switch were they able to see again for a short fixed duration (0.5 seconds). Occlusion in this sense was considered as the time during driving when the driver does not need to look at the road. • This occlusion technique was used to evaluate a Heading Control (HC) system that assisted with lane keeping. The system provided a cue to indicate the required steering wheel rotation. The results revealed that the HC system increased the average occlusion time from 1.55 s (HC off) to 2.02 s (HC on), implying that HC allowed drivers to keep their eyes off the road for slightly longer.
3. Occlude the forward scene to create a consistent eyes-off-road condition	
Perez, M. A., Kiefer, R. J., Haskins, A., & Hankey, J. M. (2009). Evaluation of forward collision warning system visual alert candidates and SAE J2400. *SAE International Journal for Passenger Cars - Mechanical Systems*, 2(1), 750-764.	• Performance was measured for responses to various icon configurations for forward collision warning systems. Participants had to complete a discrimination task. First, a forward scene was shown for a fixed interval (1.0 second) then was occluded for a variable interval (e.g., 2.5, 3.0, 3.5, or 5.0 seconds). During the occlusion interval the visual elements of the forward scene were either changed or left unchanged. After the occlusion interval, the scene was revealed again and participants were required to indicate if any element of the scene had changed. • During the occlusion intervals participants were required to complete a visual based secondary "eyes off road" task. Participants continued the secondary task until either the occlusion interval ended or an in-vehicle visual alert was activated. They were instructed that the scene would become visible 300 ms after the in-vehicle alert activated. • There were multiple performance measures, some provided significant findings (e.g., eye movement measures of the time it took for participants to look from the secondary task display to the forward view). Some measures provided non-significant findings (e.g., accuracy and response time to the discrimination task did not result in significant differences that depended on the design).

The three occlusion methods mentioned above diverge from the standard occlusion method (ISO 16673) as a result of their focus on occluding driving relevant information rather than occluding information relevant only to tasks secondary to driving. The purpose of the occlusion intervals in the standard method is to serve as a proxy to driving. This distinction is important. The third example above is the most similar to the standard occlusion method, as compared to the other two examples. The concept behind it was to measure differences between interfaces for the same system, and the task was to search for relevant information during the vision interval, either within or outside of the vehicle. The testing condition was also much more complex. Drivers completed multiple co-occurring activities. As a result, there was too much variability across participants and test conditions to provide statistically meaningful results regarding testing interface options. Although the standard method may not have been appropriate for such an assessment, it is much more controlled which enhances its reliability and repeatability.

Upcoming Collision Avoidance Systems

In addition to the relatively mature systems, there are new safety systems (e.g., do not pass warning [DNPW], emergency electronic brake light [EEBL], intersection movement assist [IMA], and left turn across path [LTAP]) that are being developed and tested using connected vehicle technology. The way that these new systems impact driving performance in general, but visual demand in particular, is far from understood. For these novel systems, there is minimal research to support standards or best practices for assessing compliance with human factors principles.

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Tutorial 2: Priority Order Index Look-Up Table for Message Prioritization

This tutorial summarizes the SAE J2395 Recommended Practice (2002) for determining the relative priority of in-vehicle messages or displayed information. Once the process described here is undertaken, the corresponding outputs need to be compared against a look-up table to determine the specific Priority Order Index (POI) for a particular message. This look-up table is available in SAE J2395. The three SAE J2395 evaluation criteria and subcategories for characterizing message priority are shown below.

> "Safety Relevance: The degree to which the information affects the safe operation of the vehicle."
>
> - Directly Relevant
> - Indirectly/Somewhat Relevant
> - Not Relevant
>
> "Operational Relevance: The degree to which the information increases the ease and convenience of the driving task, for example, by decreasing travel time and the stress associated with driving."
>
> - Highly Relevant
> - Moderately Relevant
> - Little or No Relevance/Significance
>
> "Time Frame: The degree to which the information is time sensitive, that is, the immediacy with which the information is required."[2]
>
> - Emergency: 0-3s
> - Immediate: 3-10s
> - Near Term: 10-20s
> - Preparatory: 20-120s
> - Discretionary: >120s

Note that, according to SAE J2395, a value must be assigned for each criterion. It is also important that the criteria only be evaluated and determined for each information item individually, and not based on comparison with other messages.

The SAE J2395 steps to take for setting priority order for driving environment and hazard information messages are listed below. Consult the Recommended Practice for more detail and examples.

> "4.1 Select Prioritization Evaluators
>
> 4.2 Delineate Information Items
>
> 4.3 Filter the Information Item

[2] It should be noted that J2395 does not indicate how borderline cases (i.e., timeframes of exactly 3, 10, or 20 seconds) should be treated, nor what designers should do if multiple devices have an identical score across the three criteria.

4.4 Apply the Priority Order Index

4.4.1 Determine Safety Relevance, Operation Relevance, and Time Frame Levels

4.4.2 Assign POI Rank

4.4.3 Discussion Among Evaluators

4.4.4 Average Ranks

4.4.5 Prioritize Ties

4.4.6 Incorporating New Information Items Into an Existing Rank Structure”

Additional caveats regarding SAE J2395:

- The POI table bases Safety Relevance criterion on how directly the message information correlates to increased risk of a crash, but not the severity of a crash.
- Some information messages may have the same POI rank, in which case the priority will need to be resolved, subjectively or through a separate determination process, by the design team.
- Using the SAE J2395 POI system may be less useful for more complex display prioritization situations such as determining the display order of multiple imminent crash warnings (ICWs).

Tutorial References

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Tutorial 3: Preliminary HFCV Integration Architecture[3]

1 Introduction

The purpose of this tutorial is to propose a Human Factors Connected Vehicle (HFCV) Integration Architecture model to be considered by engineers, system developers, and designers in the development of future Connected Vehicle (CV) systems. It is not intended to represent the only approach to integration, but rather to demonstrate an example approach that may be leveraged by designers. This tutorial represents the first version of the HFCV Integration Architecture released to a broad audience. This initial release is expected to generate commentary and debate among stakeholders, which will be gathered and incorporated into future versions.

The Integration Architecture governs delivery of information to the driver so that safety-relevant messages reach him/her in a timely and effective manner. In addition (and when appropriate), non-safety-relevant messages may also be conveyed to the driver to enrich the driving experience through information and entertainment services. For example, drivers may receive information about roadside attractions, travel times/delays, nearby fuel prices, restaurant hours, menus and reviews, messages from loved ones, business communications, and roadway advisories. An integrated system, which systematically controls the presentation of messages to the driver, protects against threats to safety by mitigating potential consequences of increased information flow, such as overloading or inappropriately distracting the driver's attention from the primary task of driving.

Connectivity is an enabler for rapid increases in the number and breadth of in-vehicle applications and the associated information flow to drivers—a key motivator for the creation of this Integration Architecture. Although the focus of this tutorial relates to CV applications, designers might consider using the Dynamic Integrator presented herein to control delivery of non-CV applications as well. For example, the Dynamic Integrator could readily arbitrate messages related to vehicle maintenance as part of the process; allowing all messages to be delivered as part of the controlled strategy. This integrated message delivery will allow the driver to remain connected, and perhaps entertained, without undermining safety.

The Integration Architecture proposes a system in which applications submit messages to the Dynamic Integrator; which in turn analyzes the message and its associated metadata to determine an appropriate message delivery strategy in consideration of the current driving context. The Integration Architecture identifies three integration processing stages:

- Synthesizing contextual information.
- Managing (arbitrating) messages through filtering, prioritizing, and scheduling.

[3] All the material in Tutorial 3 was originally written by Zac Doerzaph, John Sullivan, Darrell Bowman, and Linda Angell as a report submitted to NHTSA titled: Connected Vehicle Integration Research and Design Guidelines Development: Integration Architecture, Task 5. We have made some very minor editorial and formatting changes to the original report to adapt it to the tutorial format used in this document but, otherwise, no changes have been made. Cited as:

Doerzaph, Z., Sullivan, J., Bowman, D., & Angell, L. (2013). *Connected vehicle integration research and design guidelines development: Integration architecture, Task 5* (Contract No. DTNH22-11-D-00236/0001). Washington, DC: National Highway Traffic Safety Administration;

- Presenting information to the driver.

Although there are many uncertainties within these processes, the architecture provides sufficient detail to help developers consider key design factors. It is important to note that this tutorial describes the system architecture. It does not encompass requirements, specifications, standards or any other prescriptive element. The reader will not find specific algorithms and parameter values for the underlying processes behind the described logic. Although there are some areas wherein such details may be provided, the majority of the integration knowledge is not sufficiently mature to allow establishment of limits on design flexibility through prescriptive actions. In addition, many of the factors that affect the selection of specific algorithms and parameters will be platform-specific. That is, they will likely depend on the particular applications and capabilities of a given system and cannot be generically applied.

The tutorial is organized to first demonstrate the need for integration in a background discussion (Section (2). Next, in Section 3, an overview of the Integration Architecture conveys a broad description of the proposed approach. Section 4 moves into details of the applications, messages, and metadata (see section 4.1 for details) that are used by the Dynamic Integrator to make informed message-handling decisions. The Dynamic Integrator is then further described along with logic for a relatively near-term implementation in Section 5. The tutorial concludes with sections describing additional considerations, limitations and future research.

2 Background

New wireless technologies have begun transforming the driver's interaction with vehicles. Vehicle-to-vehicle, as well as vehicle-to-infrastructure communication, is enabling new and innovative development of advanced driver assistance and information systems. These advanced technologies, collectively termed "connected vehicle" systems, are expected to improve motor vehicle safety (NHTSA, 2011; Toma et al., 2010), increase mobility and sustainability (RITA, 2013), as well as offer in-vehicle entertainment (Koslowski, 2013). With the introduction of these technologies, the exchange of real-time information between the driver, the vehicle, and the world will increase because of the multitude of information sources (i.e., driver, embedded systems in vehicles, mobile devices, and roadway infrastructure-based systems) and their associated applications. A key challenge for today's driver-vehicle interface (DVI) designers is to manage the dynamic flow of information (including new information not previously available to drivers) to ensure that the driver's perceptual and cognitive abilities are not exceeded or strained (Angell, 2013).

The CV system research program focuses on the development and deployment of such technology that will "ensure safe, stable, interoperable, reliable system operations that minimize risk and maximize opportunities" (RITA, 2012). Manufacturers have already started to develop vehicle-related technologies and applications that will use this information from the connected-vehicle roadway environment. For example, commercial truckers may receive information about rest-area occupancy from network operators who may also relay information about lane closures or road conditions directly to targeted travelers on specific routes. One of the most important goals of the CV technology is informing drivers of safety and non-safety-related information in better, faster, and more effective ways.

This increased volume of information available to the driver through connectivity has created a need to assess and control the additional perceptual, cognitive, and manual demands placed on the driver. The DVI must be designed such that information is effectively served to the driver without introducing additional burdens that would compromise the driver's ability to safely operate the vehicle and that enhance the net safety and efficiency of driving (a core goal of the HFCV program). As such, the successful integration of information from numerous sources will be critical to achieve this outcome.

Integration Architecture consists of multiple technologies and applications operating independently of each other, yet co-existing in the same vehicle. For this reason, care must be taken when relaying information to the driver to ensure that no unintended negative consequences diminish the anticipated safety benefits.

3 Integration Overview

Figure 12-2 provides a context diagram that illustrates the flow of information sources into the Dynamic Integrator (indicated by the multi-colored, multi-ringed circle). The integration process ensures that messages are delivered to the driver with a controlled strategy; reducing the likelihood that a safety-relevant message goes unnoticed by the driver or is perceived as less critical; and that messages in general are provided in an appropriate manner (e.g., do not overload driver).

Figure 12-2 outlines the basic problem space, indicating that successful integration may incorporate knowledge of:

- Vehicle state (e.g., speed, fuel levels, tire pressure, oil pressure, etc.).
- Roadway environment (including CV data originating from ambient traffic and roadside information sources—e.g., trajectories and number of adjacent vehicles, proximate lane closures, traffic movement, work zone configuration).
- Driver state (e.g., alertness level) and interactive input (e.g., information requests, preference settings).
- Messages originating from applications that seek to present both solicited and unsolicited information to the driver.

Connected Vehicle data serves as a key part of the integration architecture by enabling many applications and by providing new sources of information to guide integration decisions. Generally, communications from vehicles provide information about the presence, movement, and status of other CVs in the local area, while infrastructure communications provide information about the surrounding roadway system. These sources may contain information directly related to safety, mobility, environmental, marketing, social networking, convenience, and entertainment information, all of which may be leveraged by CV applications. Based on this information, applications will each attempt to notify the driver by routing messages to the various DVIs available on modern vehicles through the Dynamic Integrator.

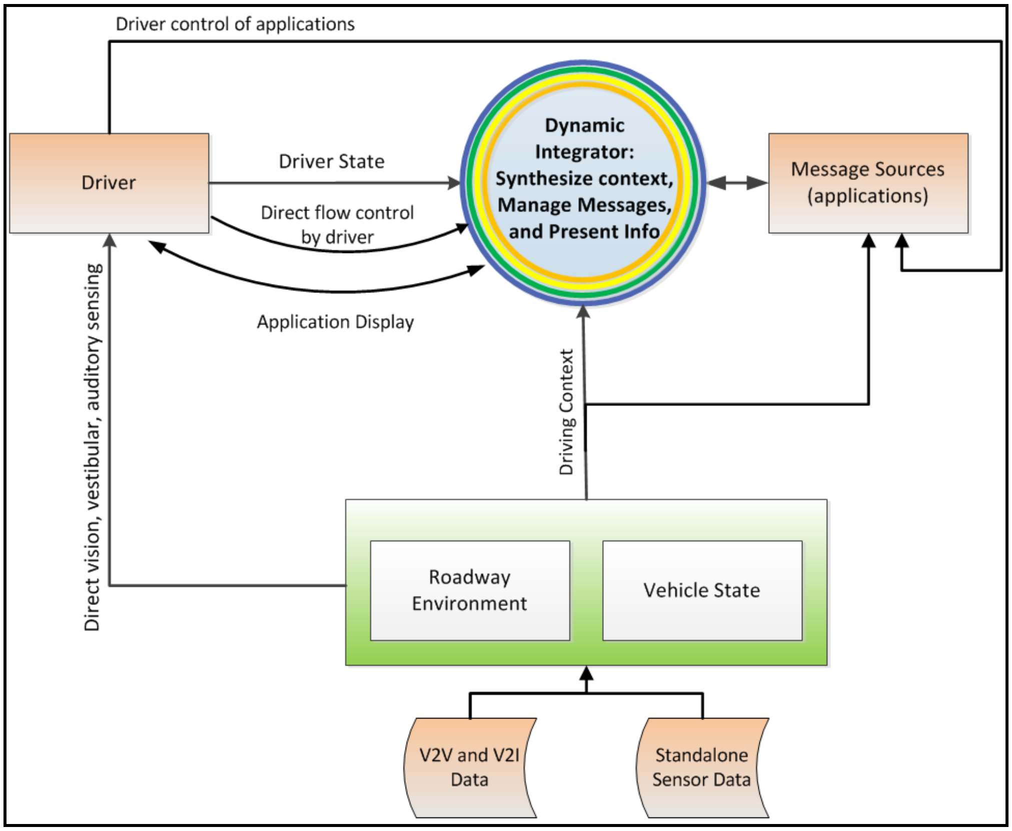

Figure 12-2. Context diagram for Connected Vehicle integration process.

Direct input from the driver to the Dynamic Integrator provides the capability to globally manage the volume and type of information conveyed to him or her. That is, while the Dynamic Integrator will control message traffic sent to the driver (based on an estimate of their ability to safely receive the information), drivers may also be provided with the ability to configure the integrator, further customizing this flow.

Illustrated by the two-way arrow in Figure 12-2, the Dynamic Integrator might also communicate directly with applications in order to administer the flow of information to the driver. If such application-level information management capability is exercised, applications will understand and appropriately respond to a small, predefined set of information published by the Dynamic Integrator. For example, it could publish information about the driver's current workload. Under high workload conditions, this information could be used by compatible applications to simplify their desired message (e.g., a detailed message regarding the cause and duration of upcoming traffic delays becomes "delay ahead"). This interaction should not be thought of as a detailed conversation between the Dynamic Integrator and the applications, but rather as information published by the integrator and accessible to the applications.

Numerous CV applications, all operating concurrently, create and submit messages to the Dynamic Integrator for presentation to the driver. With consideration for the current context, the Dynamic Integrator determines how to best present the information. This process is depicted below in the exploded view (Figure 12-3) of the Dynamic Integrator and the associated three primary integration tasks.

1. Synthesize Inputs
2. Manage Messages

3. Manage Presentation

Messages are submitted to the Dynamic Integrator by applications. Once submitted, the messages are stored (often for a very short period) in a queue for processing and arbitration. Metadata associated with each message describes attributes that are used to determine message handling strategies. The Dynamic Integrator also publishes additional data elements based on the current driving and driver context. Elements of these data are available to applications and the processes within the Dynamic Integrator. In combination, these data provide a set of attributes that enables the applications and Dynamic Integrator to collaboratively make informed decisions about what and when to present. The applications control which messages are submitted based on their detailed algorithms and the Dynamic Integrator determines if presentation is appropriate given the overall driving context. When the combined metadata satisfies all criteria of the Manage Messages process, the message is presented to the driver on an available DVI. This Dynamic Integration is performed by three primary processes:

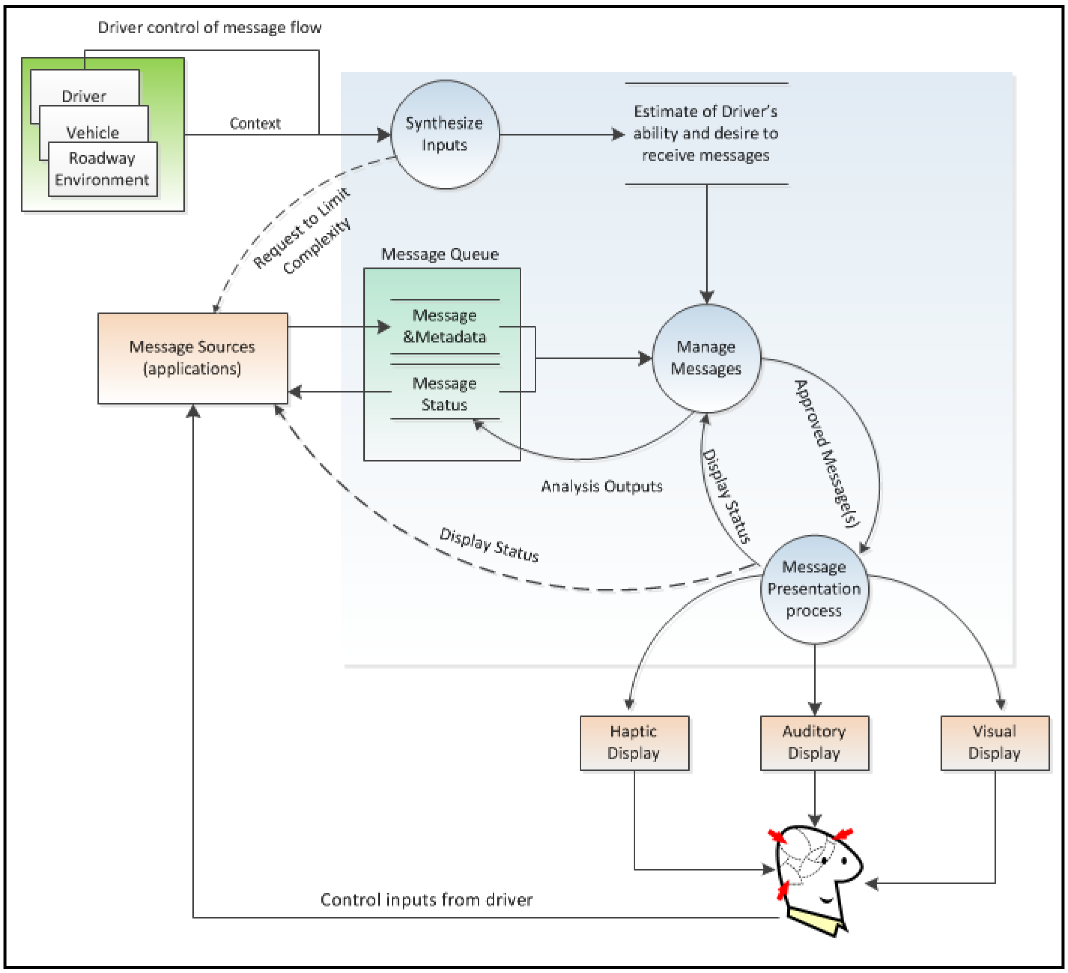

Figure 12-3. Exploded view of the dynamic integrator (within the blue box) illustrating management of three aspects of the integration architecture: synthesis of input, management of message traffic, and presentation of information to drivers.

- **Synthesize Inputs.** In this process, details of context are determined through a synthesis of various driver, roadway environment, and vehicle data. These data may be used by the integrator to make informed decisions during the Manage Messages and Manage Presentation processes detailed next. Generally, the data will be synthesized to estimate the driver's ability to safely perceive, recognize, and respond to the message, a construct referred to as available workload. Such an estimate may be based on a variety of measures, such as traffic density, speed, last interaction with the DVI, radius of roadway curvature, and perhaps direct driver monitoring systems, when available. Additional inputs synthesized may include, but are not limited to, the driver's configured integration and application settings (discussed previously) and predicted needs/goals of the driver and vehicle.

Driver needs represent the system's estimate of what type of information the driver desires. Intelligent in-vehicle systems may interface, for example, with the user's smart phone or cloud computing data center to download content about their daily schedule. This content may help the Dynamic Integrator make informed decisions regarding which messages the driver prefers to receive. Similarly, the vehicle needs represent information that the vehicle needs to convey to the driver to ensure vehicle reliability (or possibly other priorities). For example, if the vehicle is low on fuel, the Dynamic Integrator could use this information to elevate messages pertaining to upcoming fueling opportunities.

- **Manage Messages.** The Manage Messages task is at the heart of the Dynamic Integrator and is the primary focus of this tutorial. During this task, messages are arbitrated to determine which might be filtered (i.e., discarded for current time step), dynamically adjusted in relative priority, and scheduled for presentation to the driver. Details of this process are further broken down in Figure 12-4, which depicts how a message must pass through each of these three processes before presentation.

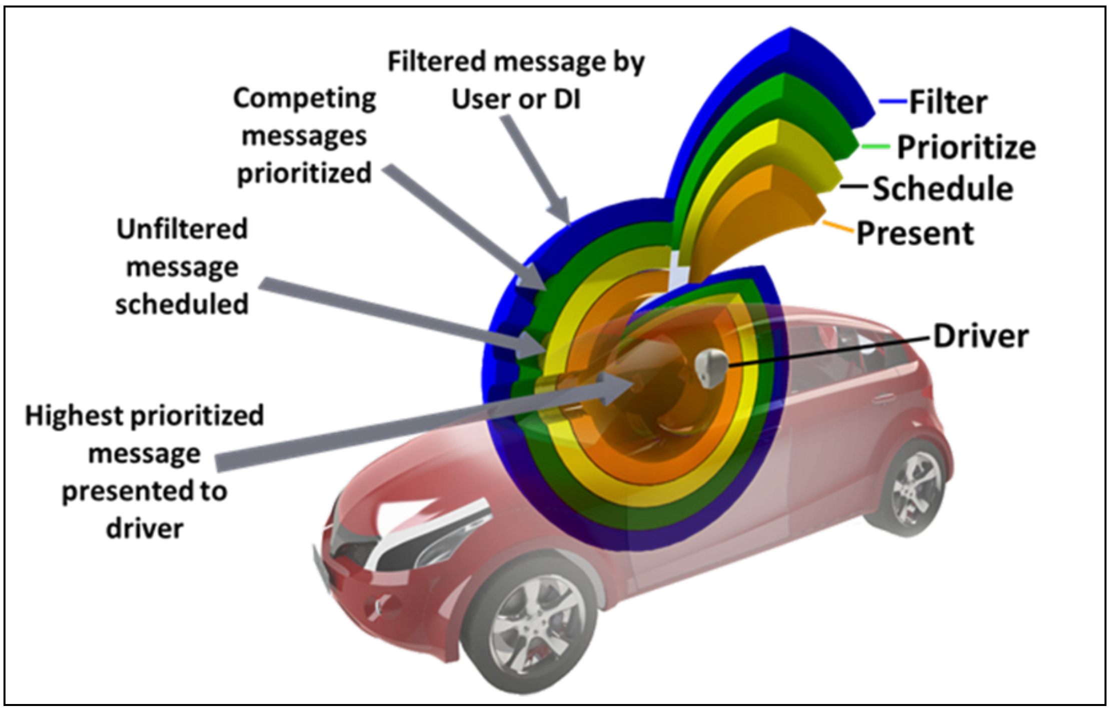

Figure 12-4. Connected Vehicle dynamic integrator model.

  - **Filter.** Messages that are not appropriate, given the current driving context, may be immediately blocked and not processed by the remaining integration stages for the current processing cycle (they may be reconsidered by the process at the next time step). Filtering will occur based on user settings or when driving conditions indicate it is unsafe to provide a given message.
  - **Prioritize.** When numerous applications are operating, multiple messages may be simultaneously submitted. This is particularly true if a long message or string of interactive messages has been blocking access to the DVIs (e.g., driver is actively

navigating a menu structure on the DVI). When multiple messages are cleared by the filter, a prioritize process will determine the relative importance of the messages and assign presentation order accordingly. Priority ordering itself, however, does not exclusively determine when a message will be presented.

 - **Schedule.** Timing is the function of the scheduling process that assesses the metadata and context information to determine when each message should be presented. This process controls message cadence and ensures that drivers maintain the capacity to receive information while focusing on the primary task of driving. In some cases, the schedule process may allow certain high-priority messages to interrupt lower priority messages (e.g., in the case of an imminent safety warning). The process also has the ability to schedule messages of equal priority at or near the same time, particularly if their presentation strategies allow the driver to process both messages effectively (e.g., using two different display modalities).

- **Manage Presentation.** In this process, messages that have been cleared for delivery are analyzed and distributed to the appropriate DVIs for information rendering. The Manage Presentation process tracks the use of all DVIs and publishes the information for the applications and the Manage Messages process to use. This status information contains details of which applications are currently using the DVI and, when allowed by designers, which types of other applications may share access. For example, consider a navigation application that is displaying map content across the large center stack screen. The Manage Presentation process may have provisions for allowing a small overlay to appear in the screen corner; which can, for example, display the current speed limit as populated from an in-vehicle sign application.

Overall, messages are submitted to the Dynamic Integrator by applications with the intent of conveying a message to the driver. While there are a number of processing steps, ultimately, the Dynamic Integration results in one of the three following outcomes for each of these messages:

1. Send the message straight through for immediate presentation.
2. Delay the message resulting in:
   i. Later presentation.
   ii. No presentation when message becomes obsolete.

For presented messages, the Integration Architecture facilitates appropriate display of content on the available resources. It is important to note, for simplicity, the Integration Architecture is presented as a set of steps that may appear to be sequentially executed. Although useful for exposition clarity, many of these processes are actually conceived as concurrent processes that are event-driven. They are triggered by message transmission, refresh cycles, or changes in driving context. Thus, all processes may act on messages asynchronously as they arrive, or synchronously with a defined evaluation cycle. As with many vehicle-safety systems, it is expected that the Integration Architecture's evaluation cycles will occur many times a second; for example, 10Hz has been accepted as reasonable cycle time for CV safety-message transmission (SAE, 2010).

It should also be mentioned that the message queue, as depicted in Figure 2, is a storage location in which messages are processed before they are cleared for display. During this processing, messages are indeed prioritized as suggested by the name "queue"; however, the Integrator can allow multiple messages to be presented during any one cycle (e.g., both messages meet the necessary criteria for display and do not conflict with each other). There is not a one-to-one relationship between a full Dynamic Integrator refresh cycle and the presentation messages.

With the full system context provided by this overview, the remaining portions of the tutorial will focus in on the details of individual components to further clarify operations. This will begin with a discussion of the applications and subsequently trace through each process of the Integration Architecture.

4 Message Sources (i.e., Application Processes)

Applications for the CV can address topics from traditional transportation areas such as safety, mobility, and environment to newer areas such as convenience, entertainment, and marketing. The Dynamic Integrator cannot be tasked with knowing and evaluating the low-level details of each application or the content of the messages that they produce. Instead, the Integrator must be directly provided with specific information about the data it will handle. That is, it relies on metadata associated with messages. This metadata, described later in this section, contains key pieces of information that provide the basis for message arbitration and display. The majority of the metadata is statically determined during application design with limited additional metadata determined dynamically.

As indicated previously within Figure 2, applications submit messages and metadata to the Dynamic Integrator, where it is inserted into a queue with other submitted messages. While in queue, the metadata is analyzed by the Dynamic Integrator with consideration for the present context. The results of this analysis are published for other processes, including the application process itself. For example, the filter process within the Manage Messages task may determine that a message is too complex for display, given the current context. At this time, it will update the message status indicating rejection for complexity. This Message Status, in turn, may be read by the application that can wait for the message to be accepted (when the current context is more favorable), cease message submission, or perhaps resubmit a simplified message, if available.

Such message tailoring may also be performed prior to submittal to the Dynamic Integrator queue. For example, information published by the synthesize inputs and presentation processes might be presented to applications in order to inform the application's messages-creation process. More specifically, the synthesize inputs and presentation layers can make a limited set of attributes that reflect the current driving context (or driver state) available to the applications (dashed lines in Figure 2). This provides applications with awareness of the current capacity of the driver and availability of interfaces; which may help determine which messages should be submitted. An application could then adjust its message output (e.g., simplify content) to increase the likelihood that it will reach the driver without being filtered or delayed. Enabling of this functionality is predicated on the assumption that applications appropriately respond to such published information and do not artificially manipulate, for example, their metadata to alter the priority of a given message.

Applications are likely to post messages around the time they should be displayed. Consequently, messages should normally flow as quickly as possible through the integrator, resulting in a display to the driver. However, if displays are shared by applications, they may occasionally be unavailable (e.g., locked out due to a higher priority message). There may also be occasions in which a delayed message remains in the queue sufficiently long that it becomes irrelevant (e.g., "rest area ahead" message once the window for taking the exit has been passed). The application can stop submitting messages that become irrelevant prior to display.

Another important distinction in applications relates to the origin of a message: solicited versus unsolicited. Solicited messages include applications such as tuning the radio, wherein each message is provided in response to a specific driver request. Unsolicited messages are presented without a direct request from the driver. These unsolicited messages are common across the envisioned CV applications, and may provide information ranging from services at an upcoming exit to unexpected traffic delays on the roadway ahead. While collision warnings (a type of unsolicited message) have considerable research support, the impact of other types of unsolicited messages on driver performance is not well understood. Caution should be exercised to ensure that such messages do not inappropriately distract the driver.

Messages may vary considerably in their content and complexity. A simple message may update the artist's name on an internet radio station located on a small display within the instrument panel. More complex messages (e.g., upcoming traffic delay or new route suggested) may subsume an entire display. Such complete control of a display by an application is likely when a driver is performing an ongoing or multi-step interaction (e.g., navigating a menu structure). During these scenarios, the Message Management can help ensure that messages do not inappropriately interrupt the interactive activities.

To enable these integration processes, the messages must include information that enables the Message Management to make decisions. This information, appended to each message by its associated application, is referred to within this tutorial as metadata and is further described next.

4.1 Message Metadata Overview

A list of metadata can be associated with each CV message submitted by an application. It provides the information needed to properly filter, prioritize, schedule, and present the message. Such a list of metadata is thus likely to consist of two sub-parts: (1) a list of values that are established in advance (at the time messages are developed and tested for use within the CV system); and (2) a list of values that may be established in real-time as the vehicle is being driven, based on certain values acquired from vehicle, infrastructure, or driver data. To assist in visualizing this, it might be graphically depicted as, literally, a list of data fields (Figure 12-5).

Figure 12-5. Hypothetical diagram of a list of metadata accompanying a CV message.

The colored boxes above are intended to represent metadata fields that carry values of variables. The first six fields in the list above (yellow, green, turquoise) might, for example, represent the pre-computed values (determined by testing done in advance on CV messages, and stored as an embedded part of each CV message). The second six colored boxes in the list above (dark-red, tan, lavender) might represent values that are derived in real-time by the applications.

The static metadata construct is not new as evidenced by methods used to characterize message priority offered by both the Society of Automotive Engineers (SAE, 2002) and the International Organization for Standardization (ISO, 2004). In these procedures, the following message metadata are explicitly quantified:

- **Safety relevance** (SAE)/**Criticality** (ISO). This is the degree to which the receipt of the message affects the safe operation of the vehicle. SAE distinguishes three levels of safety relevance (directly, indirectly, and not relevant). ISO distinguishes four levels of criticality (severe or fatal injury, injury or possible injury, no injury but damage likely, and no injury or damage likely).

- **Operational relevance** (SAE only). This identifies the degree to which the information increases the ease or convenience of the driving task. Three levels are distinguished: highly relevant, moderately relevant, and not relevant.
- **Time frame** (SAE)/**Urgency** (ISO). This identifies the degree to which the information is time-sensitive in the sense that it reflects the time in which the driver must see the message, presumably in order to take appropriate action. SAE distinguishes five levels of time frame, and ISO distinguishes four levels.

These standards provide a reasonable starting point that might be leveraged to establish a priori baseline message priorities. They are, however, currently limited in their ability to specify how these factors are assigned and weighed to determine a message’s instantaneous priority in a constantly changing real-time environment. This is particularly true in the CV context, wherein numerous messages are arbitrated in an ongoing and context-dependent manner. Several other kinds of metadata about messages might also help in the management and control of how and when a message is presented to a driver.

There has been very limited previous literature and discussion of the ways messages might be characterized to permit successful DVI integration. Traditionally, most messages are simply displayed immediately and on a single interface/format. This does not consider future vehicles, and particularly CVs, in which an ongoing dialog of messages may be received by the driver across several different interfaces. The effort needed to characterize and enumerate the various attributes of messages relevant for successful integration is a reasonable ongoing research program. However, at present, there is sufficient knowledge to suggest some metadata elements for consideration, the use of which will be demonstrated through the subject Integration Architecture.

In most instances, the elements are determined ahead of time, when a message is developed—and when it is tested by its developer to make sure that it meets relevant human factors guidelines that are applicable. It is assumed, for example, that messages to be presented within a CV system would be pre-tested for their compliance with applicable distraction guidelines, such as the recently released NHTSA guidelines that may be voluntarily applied to visual-manual interfaces of vehicle-embedded electronic devices (NHTSA, 2013).

4.2 Exemplar Message Metadata

Table 12-9 provides a summary of possible message metadata followed by a brief description of each data element. It is the purpose of this table and the subsequent descriptions to provide example metadata elements for consideration by designers to be used in the subject architecture. This is by no means a complete list, nor is it universally applicable, appropriate, or justifiable for every CV platform. The reader is reminded that this tutorial is being drafted to assist designers in the development of a Dynamic Integrator, not to provide a generically useful and validated integration method or a detailed implementation design.

Table 12-9. Possible fields of message metadata for CV messages.

Field	Set	Description	Coded Levels	Processed By	Sources
1	A priori	ID	• Unique Message ID	• All	
2	A priori	Application Type	• TBD – platform specific	• Filter • Prioritize	
3	A priori	Message Type	• Safety • Mobility • Environment • Entertainment • Social Networking • Services/Marketing	• Filter • Prioritize • Schedule • Present	NHTSA, 2011
4	A priori	Origin	• Solicited • Unsolicited	• Prioritize	Holmes et al., 2013
5	A priori	Safety Relevance	• Yes-Direct • Yes-Indirect • No	• Prioritize	SAE, 2002
6	A priori	Time to Respond	• Time measured from testing	• Schedule • Present	
	A priori	Message Demand	• Additional workload imposed by message	• Filter • Prioritize	
7	A priori	Target DVIs	• Specifies the DVIs to display message and indicates whether each DVI is required or optional.	• Schedule • Present	
8	Dynamic	Expiration Time	• Time	• Prioritize	SAE, 2002
9	Dynamic	Message Age	• Time	• Prioritize	

1. **Message ID.** This field would contain a unique identifier for a message. It is used by the Dynamic Integrator to address messages during processing.
2. **Application Type.** This field identifies the type of application generating the message. It may be used to enable user filtering of particular types of information as well as several other processes of the Dynamic Integrator; as described later in this tutorial.
3. **Message Type.** This field would contain a classification of message type based on message content. It may be used to enable user filtering of particular types of information as well as several other processes of the Dynamic Integrator; as described later in this tutorial.
4. **Origin.** This field identifies whether or not the message is a direct result of a request from the driver. In the absence of any other priority, messages that are solicited will be presented prior to unsolicited messages.
5. **Safety Relevance.** This field would contain a code that reflects the SAE Safety Relevance (as discussed above). The other components (operational relevance and time sensitivity) of the SAE J2395 will be computed during the prioritize process based on real-time data (see Figure 12-9).
6. **Time to Process and Respond to Message.** This field carries a measure of time that reflects the actual time period a driver needs to receive the message (read it or hear it or otherwise sense it), process it for comprehension, and then respond to it, all without compromising safe driving.
7. **Message Demand.** This field carries a measure of the amount of additional demand imposed by processing and responding to the message (which would be assessed at the time of its design and development).

8. **Target DVI Address.** There are significant differences in the constraints imposed on the integrator by a message's DVI requirements. Two audio messages, for example, cannot be presented simultaneously without the risk that one message might mask another. On the other hand, visual displays can present more than one piece of information at the same time, provided they do not occupy the same display screen area. This metadata element can include multiple DVIs (and modalities), along with indications of whether each DVI is required or optional. This will ensure that messages requiring multiple DVIs are presented appropriately (e.g., collision warning on both audio and visual displays). It will also allow other types of messages to have a flexible display method (e.g., use auditory if available, but to only use vision when unavailable, like when the driver is listening to music).
9. **Expiration Time.** To enable the Message Manager to act in a way that is consistent with the SAE J2395 notion of urgency, this field, provides the message "shelf-life". Some messages may have limited relevance as time passes, while others may be relevant for an entire trip. If such messages are buffered or delayed in a queue, they may become irrelevant over time. Some messages may become irrelevant as a vehicle passes out of an area. For example, warnings about an icy roadway surface may apply to a limited section of a roadway. Once a vehicle passes through the area, such a warning may become obsolete or even detrimental. This data element is populated by the application based on the specific needs of the message content and is updated in real-time based on data processed by the application.
10. **Message Age.** This field would reflect a measure of how long the current message has been waiting in the queue. In the absence of a clear priority, messages will be presented in a first-come-first-serve order.

5 A Dynamic Integrator Model

In a reiteration of an underlying message throughout this tutorial, the Integration Architecture presented herein forms the basis from which developers may create a prototype Dynamic Integrator. It partitions the processes and establishes a framework for a general approach that may be widely adaptable; however, we should acknowledge that new approaches may indeed become more suitable as application software and hardware platforms evolve. As such integration systems become engineered and prototyped, it is certain that refinements and improvements will be made to the material conveyed thus far and throughout the remainder of this discussion.

To assist developers with the realization of refined Integration Architectures, the following section provides some additional discussion of the Dynamic Integrator parsed by its three distinct processes: (1) Synthesize Inputs, (2) Manage Messages, and (3) Manage Presentation. This discussion is accompanied by an example of a near-term Dynamic Integrator. This phrase "near-term" implies the relatively simple structure and logic of this example. That is, the example presented, with some research and development, could be deployed in the relative near-term; however, it may provide a more conservative integration strategy than would be possible with more research and implementation of a more sophisticated architecture. Within the discussion of each process, the example is followed by additional considerations that may help designers work toward a more capable integration architecture of the future.

5.1 Synthesize Inputs

The main purpose of the Synthesize Input process is to characterize the current driving context, thus serving as the basis for the decisions of the Manage Messages processes. This current context is parsed into four primary sub-processes, each of which measures or estimates key attributes of the Dynamic Integrator:

- **User Configurations**, which gathers system settings that control how and when messages may be presented to the driver.
- **Workload Estimation**, which assess the driver's ability to receive messages based on prevailing conditions.
- **Driver Needs Prediction**, which predicts the goals and desires of the driver based on information available (e.g., driving patterns, anticipated destination, and calendar downloads, etc.).
- **Vehicle Needs Prediction**, which predicts vehicle systems that will need the driver's attention (e.g., low oil pressure, maintenance due, etc.).

Figure 12-6 provides an overview of the primary sub-processes within the Synthesize Inputs layer. Each of these processes captures and analyzes data from multiple sources within the vehicle. In-vehicle sensors collect real-time information about the vehicle state and can include:

- Chassis-related (e.g., braking, steering, vehicle stability, tire pressure).
- Safety-related (e.g., air bag actuation, seat belt, occupant presence, blind spot, lane departure, parking, headway).
- Driver-related (e.g., steering, throttle, DVI interaction, system settings), roadway (e.g., traffic density, estimated curvature, roughness, etc.).
- Environmental-related (e.g., ambient light, ambient temperature, humidity, precipitation).

From these data, processes generate output useful to the management of messages in the subsequent Dynamic Integrator layers.

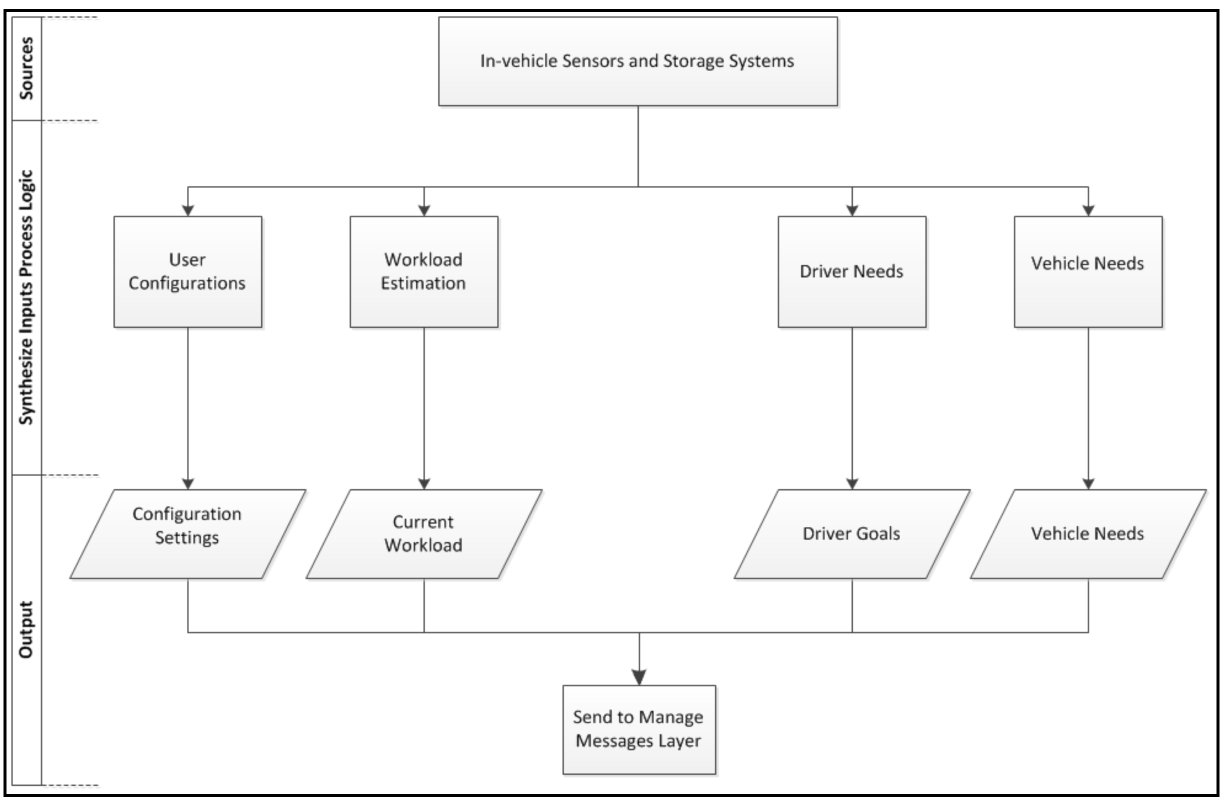

Figure 12-6. Overall framework for the Synthesize Inputs layer.

The User Configurations captures the current user-defined settings relevant to integration. The driver is expected to have the ability to set certain filters, based on personal preferences. For example, these filters might pertain to whether or not marketing messages will be allowed for presentation. These data on configuration settings are stored on an in-vehicle system and, for the purposes of this illustration, are captured as part of the in-vehicle sensor suite. The Dynamic Integrator will access these settings when making decisions on whether or not a message should be presented.

The Workload Estimation might combine information about the demands of the primary task (e.g., the driver's control inputs, traffic density, etc.) and secondary tasks (interface inputs, direct driver monitoring systems, etc.) to estimate the total current workload. This workload estimate is compared to the workload required by a pending message to determine whether the driver has sufficient capacity to respond without impacting safety. Workload estimation in a real-time system is complex and not particularly well-defined at the present state. Given its importance to the presented model, additional discussion is provided in the next section (Section 5.1.1).

The Driver and Vehicle Needs Assessments may be computed from analysis of information such as:

- Historical data (e.g., driving and interface use patterns).
- External devices (e.g., the key fob will identify the current driver, and the driver's phone, if linked, may upload calendar events, including purpose of current trip—such as driving to the airport for a scheduled flight).
- Vehicle state sensors.

Driver Needs and Vehicle Needs sub-processes pull together data, which would otherwise remain separate, in order to assist the Manage Messages process with intelligently determining if an incoming message is of high operational relevance for the driver-vehicle system. This driver-vehicle system must be considered as whole—driver-in-partnership-with-the-vehicle and in the context of road, traffic, and environment. In the near-term, this may consist of using preset relationships to identify scenarios in which the driver or vehicle needs match to a given message. These "matches" could occur between message content and currently existing needs/states, or with those that are emerging or projected (e.g., based on currently-driven route, for example, and/or based on events that have been detected by CV sensors up ahead).

The Synthesize Inputs layer is charged with gathering information from various sources and distilling it into content that may be used by the Manage Messages process. This distilled information is application- and vehicle-platform dependent, which precludes detailed discussions of the specific measures and algorithms applicable to these sub-processes. The user-configuration sub-process is primarily a pass-through in which configuration settings of a specific system are read and then provided to the Manage Messages process. The Driver and Vehicle Needs sub-processes are highly dependent on the information available on a given platform (and may not be part of the initial systems). Finally, the workload sub-process is central to the Integration Architecture, and as such will be discussed in further detail below.

5.1.1 Exemplar Logic for Workload Estimation

The following section provides the logic for outputting an estimate of driver workload within the Dynamic Integrator example. There are numerous driver workload estimators proposed in the literature (Alders et al., 2012; Ohm & Ludwig, 2013; Prakah-Asante et al., 2010; Son & Park, 2011; Yoon Sook et al., 2010; Zhang et al., 2004); therefore, this section will not propose a specific method, but instead, provide the framework that a driver workload estimator should work within.

A driver's capacity may be best predicted by estimating the current driver workload through analysis of available data from the vehicle, environment, and driver. Initially, such workload estimates can be simplistically determined (e.g., vehicle static versus vehicle in motion) and generically applied across messages, regardless of intended delivery strategy. As knowledge is gained, these workload assessments can become more refined by considering numerous additional measures and the relative demands on specific attributes of the driver's perceptual, cognitive, and physical resources. This could allow leveraging of driver resource capacity over a broad range of driving contexts, thus allowing users to safely interact with the system more frequently.

Given the current state of knowledge, a near-term example of driver workload estimation discussed in this section relies on simple estimates of the driver's ability to receive messages based on traditional vehicle sensors. This vehicle contextual data allows the output of the Dynamic Integrator to be informed and responsive to the ongoing driving situation. After the example is provided, a subsection is devoted to discussing additional considerations for future, more complex, theoretical methods for estimating workload.

Figure 12-7 illustrates a hypothetical framework for the Synthesis Inputs layer. Driver State includes a simple overall estimate and does not take into account differences across the driver's resources. Vehicle State includes estimates of vehicle dynamics and stability. Roadway Environment State includes estimates of traffic density, roadway type, roadway surface conditions, and ambient environmental conditions.

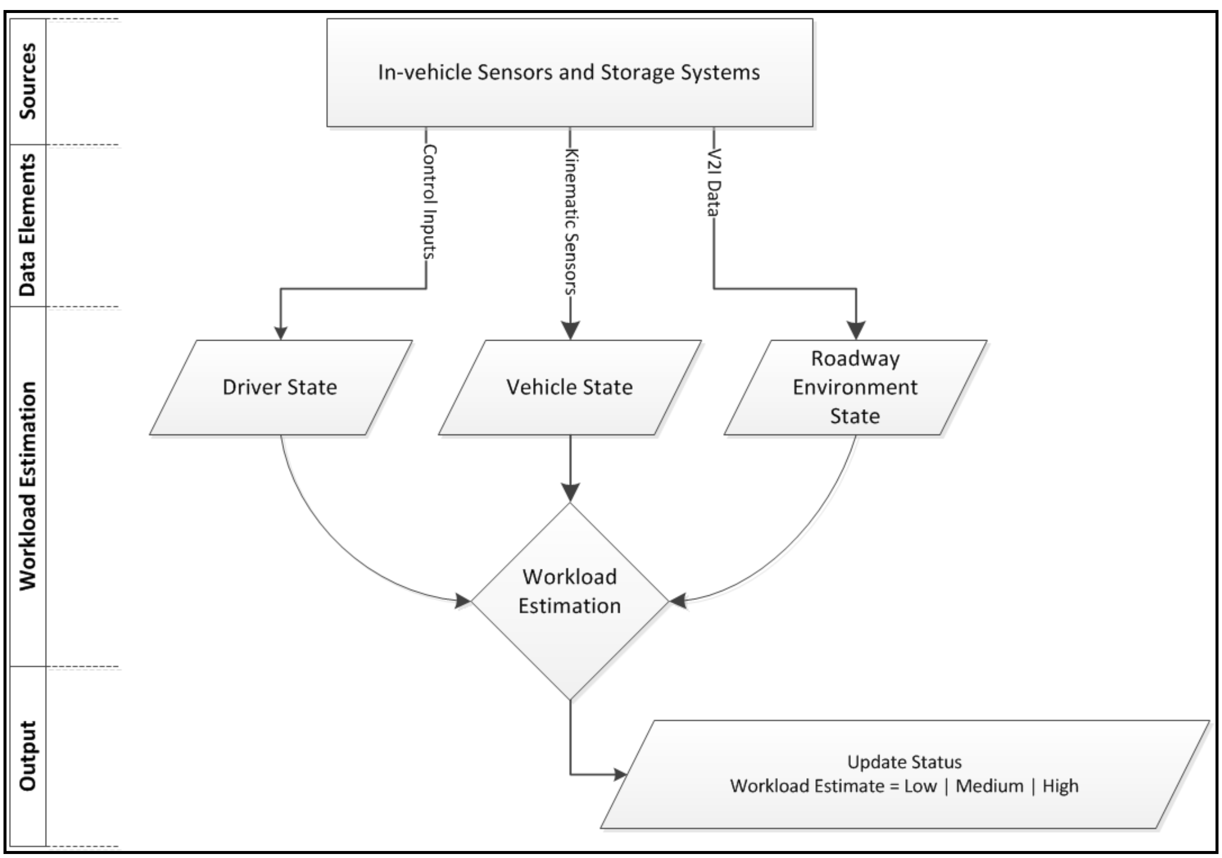

Figure 12-7. Hypothetical logic for synthesis for workload estimation.

The primary outcome of the workload process is an estimate of the driver's ability to safely receive a message. This is computed as a measure of workload, or the extent to which the driver is currently tasked, and provided to the Filter sub-process within Manage Messages process. This process will use the estimate to determine whether a message should be forwarded to the next process or blocked to avoid overwhelming the driver (raising the workload over a preset threshold).

5.1.2 Additional Considerations for Synthesize Inputs

The Synthesize Inputs process deals with predicting driver workload in a real-time context based on information available to the Dynamic Integrator; a topic that is not mature. As such, it is worth discussing some additional considerations that could enable more accurate estimates of the driver's ability to receive messages. The applied synthesis example presented previously was a simplistic representation of the driver's resource capacity based on readily available inputs. Wickens' (2008) Multiple Resource Theory and other workload models might serve as a basis for establishing a more complex message delivery technique that maximizes the driver's cognitive resources. Application of such workload models may allow for the presentation of multiple messages simultaneously without compromising safety.

In its simplest form, a single load estimate might be sufficient to capture a driver's current capacity to respond to messages. This might, however, also be refined to distinguish different kinds of driver loads such that some kinds of loads might be considered somewhat independent of other loads (e.g., verbal versus perceptual; Wickens, 2008). For illustration, darkness might increase perceptual load, causing the driver to focus more attention from the visual process to compensate for reduced visibility, without affecting the driver's ability to understand spoken-word messages. This suggests that a more sophisticated version of Synthesize Inputs might manage a multi-dimensional picture of a driver's ability to process certain classes of information. Such compartmentalization of driver processing capacity is rooted in a long history of driver workload research (e.g., Engstrom, Johansson, & Ostlund, 2005; Lavie, 1995, 2005; Lavie, Hirst, de Fockert, & Viding, 2004; Leibowitz & Owens, 1977; Recarte & Nunes, 2000).

The key purpose of this synthesis is to gain some idea of the degree to which the driver may be able to receive and respond to messages. Roadway environments such as rough pavement, poor weather, limited visibility, tight radius of curvature, and high traffic density will likely elevate the level of focus needed by the driver to safely drive. Some of this roadway information can be derived directly from CV message traffic, while others may come from vehicle sensors such as speedometers, accelerometers, radar, and machine vision.

For example, either the number of basic safety messages or the number of radar targets could be used as an index for traffic density; this, in turn, could be used to adjust the workload estimate. A step deeper, the relative speed and speed variance of adjacent vehicles captured by these sensors could be used as an indicator for traffic volatility, which could have additional implications on the driver's ability to receive messages. Additional measures of driver engagement, such as rapid steering and lateral acceleration, could indicate windy roads that may be both demanding and somewhat unforgiving due to limited sight distance. In such a situation, it may be prudent to temporarily reduce message flow rate to that driver. Other examples could be given as well (e.g., rain-sensing wipers, if on, indicate the presence of precipitation in the roadway environment, increasing load on the driver and a need to reduce message traffic to the driver, and so on). Unfortunately, there is limited research to date that relates such driver, vehicle, and roadway environment factors to the ability of a driver to receive messages.

5.2 Manage Messages

The Manage Messages process arbitrates numerous application messages to determine whether, when, and how a given message may be presented. The primary goal of this process is to control the flow of information originating from multiple sources in a manner that ensures content is safely displayed to the driver without being masked (or otherwise unnoticed) because of competing content from another source. This is accomplished through the embedded filtering, scheduling, and prioritizing sub-processes. Each of these processes analyzes specific elements of the message metadata in consideration and the contextual data published by the Synthesize and Presentation processes to control the message delivery strategy.

5.2.1 Filter Messages

The initial process within Manage Messages filters information so that messages are rejected if they are either: (1) explicitly prohibited by the driver through a direct configuration setting; or (2) impose an inappropriate level of additional load on the driver, given the current driving context.

Filtering based on configuration settings. The first basis of filtering involves explicit prohibitions that might be established by the driver. For example, a driver may wish to adjust receipt of some classes of message, just like smart-phone users can configure either the phone's operating system or specific applications to suppress presentation of some notifications. To accomplish this, the user may adjust the Dynamic Integrator configuration settings to suppress messages based on individual applications, application type, message type, or other criteria as desired. Filtering by application type requires assigning each connected vehicle application a class designation. For example, applications like Instagram, Twitter, and Facebook might be classified as social networking; applications relaying traffic operations data (e.g., lane closures, road conditions, and/or travel time) might be broadly classified as roadway information. Filtering could provide the driver with a means to independently suppress presentation of messages from all applications belonging to one or more of such classes.

Because some applications could transmit a range of messages that vary in importance, it might also be appropriate to implement filtering by message type. For example, a roadway construction application might have a variety of messages ranging from long-range strategic (e.g., future construction planned on current roadway in the coming months) to tactical (e.g., construction flagman actively directing traffic ahead). By filtering on message type, the application may still allow the tactical messages to be presented while blocking strategic messages.

Filtering based on estimated driver workload. The second reason to filter or withhold messages from the driver occurs when the added demands of specific message delivery on a driver's current workload could elevate the risk of a traffic conflict. That is, if the message is likely to divert the driver's attention momentarily, it may increase the risk of overlooking important information in the roadway (e.g., a car pulling out of a driveway). Unless the message is directly targeted at improving safety, it might be reasonable to discard it and avoid the possibility of increasing crash risk. An example of this filtering would be to restrict unsolicited notifications when driving in volatile urban traffic.

Note that the filtering process need not directly "know" that the nearby traffic is dense. The Synthesize Inputs process understands that traffic density affects the amount of targets a driver must keep track of and establishes that the driver's workload is high. Filter simply blocks messages that are not permitted under specified workload levels.

5.2.1.1 Exemplar Filter Process Logic

The chief purpose of the Filter is to determine, based on metadata and the driver's current load level, whether to block the message or to pass it along to the prioritize process. If a message is blocked, no further processing of that message will occur until the next refresh cycle; in which the filter will reevaluate the message based on the updated information. An example of a processing logic is given in Figure 12-8.

The outputs of this process, for a message that is not filtered, are an update of the Message_Filtered status to "no" and forwarding to the Prioritize Process. Messages that are filtered have their Message_Filtered status set to "yes" and an associated reason of either "User Configurations" or "Exceeds Workload," depending on the filter enacted. Applications may read this information and decide whether to cease submittal of the message or to continue to submit and await a change in the filters to permit message passing.

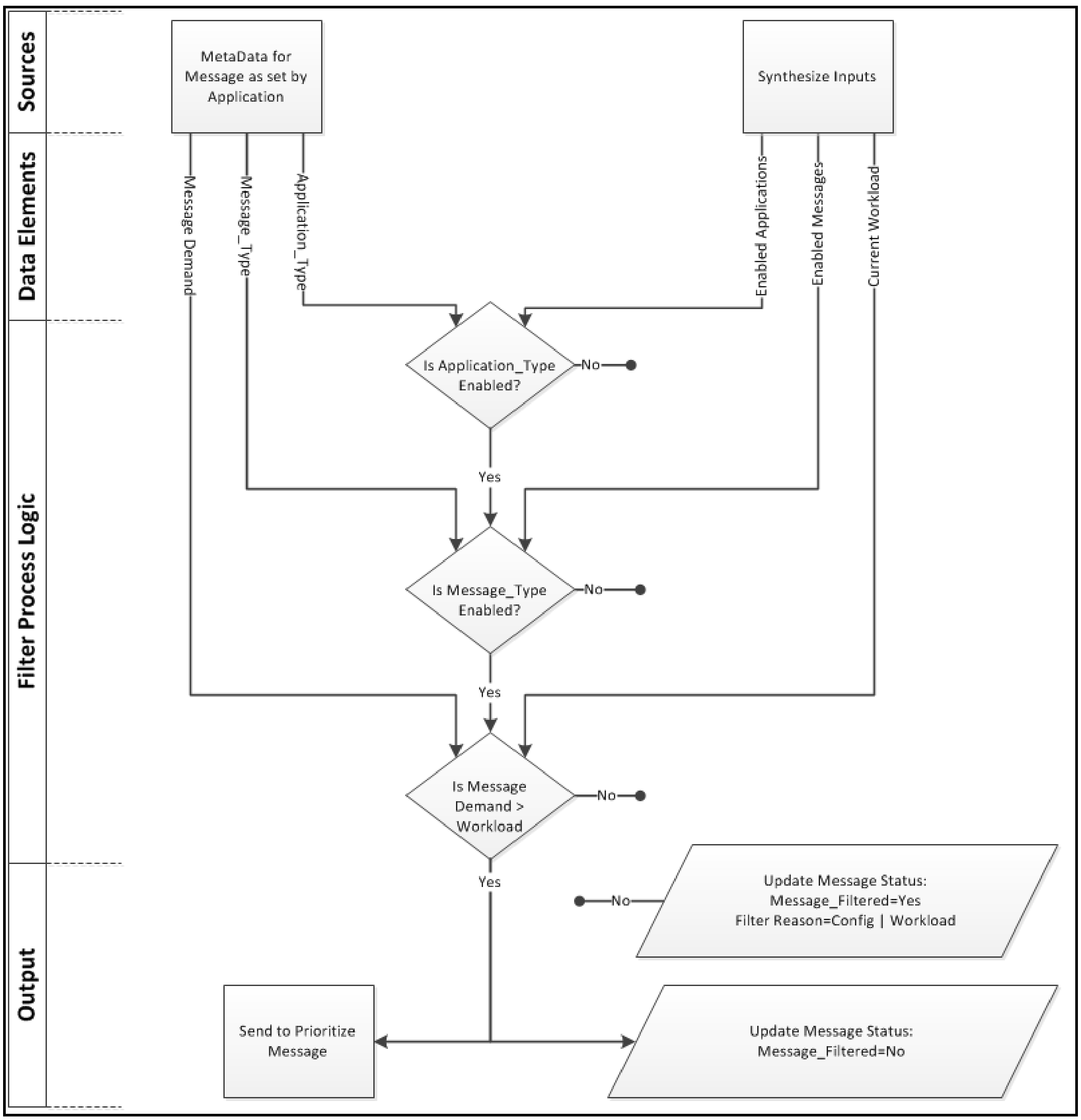

Figure 12-8. Example of a Filtering process applied to messages that are intended for the driver.

5.2.2 Prioritize Messages

Methods exist for determining static (context independent) message priority (SAE, 2002; ISO, 2004). The Prioritize process augments this assignment of baseline priority with considerations for the current driving context to determine the real-time priority relative to competing messages. Messages are essentially ordered by priority within the message queue before being passed to the scheduling process; which will determine the exact timing of presentation.

In general, competing messages will be prioritized based on the SAE principles of Safety Relevance, Time Frame, and Operational Relevance. For a given message, a real-time priority order index will be computed relying on the definitions of SAE J2395 (2002) and then used to determine relative message ordering.

Safety Relevance is the degree to which information affects the safe operation of the vehicle. It is set a priori by developers in the design of the message and may take the standard three levels of:

- **Directly Relevant.** Information contains direct safety information. Includes any item that has as its primary purpose communication of information that is designed to reduce the likelihood that the driver/vehicle and/or other driver/vehicle and/or pedestrian will be injured/damaged.
- **Indirect/Somewhat Relevant.** Information is not directly safety relevant as defined above. However, the information, if processed and responded to by the driver, may reduce crash risk by reducing error or exposure.
- **Not Relevant.** Information item is neither directly nor indirectly safety relevant as defined above. No known change in crash risk due to the presence of safety information, a change in exposure, or a change in safety-related driver error.

Time Frame is computed in real-time by the prioritize process based on the expiration metadata computed by the application. Essentially, message expiration metadata contains a countdown timer that represents the remaining time window in which the driver is expected to respond to the information provided. Thus, messages that will become irrelevant sooner will migrate to the top of the queue. Time Frame, or the immediacy with which the information is required, is clustered into the standard bins by the prioritize process.

- *Immediate:* 3-10s
- *Near Term:* 10-20s
- *Preparatory:* 20-120s
- *Discretionary:* >120s

Operational Relevance is also computed in real-time by the prioritize process; however, its formulation is not as refined. Operational relevance is computed based on data from the message metadata and Synthesize Inputs process. The message metadata Message Type and Origin (solicited versus unsolicited) is compared to the Driver and Vehicle Needs provided by the Synthesize Inputs process. The prioritize process analyzes the two sources of information looking for, and assessing, the strength of “matches” between the purpose of the message and the needs of the driver and/or vehicle. The matches are then inserted into the following classifications, which represent the degree to which information increases the ease and convenience of the driving task:

- **Highly Relevant.** Information that, if not received, will cause the driver inconvenience/expense such as delay, error, or vehicle damage.
- **Moderately Relevant.** Information that is not highly relevant, as defined above. It may improve the ease and convenience of the driving task, but will not likely result in inconvenience or expense to the driver if not present.
- **Little or No Relevance/Significance.** Information that will not impact the ease and convenience of the driving task.

The formulation of safety relevance, time frame, and operational relevance allows the standard Priority Order Index table [Tutorial 2 and SAE J2395 (2002)] method to be applied to all messages in the queue. After application, the queue will be rank-ordered by priority. In some situations (e.g., multiple messages containing similar content are submitted), priority ties are likely to occur. In general, these ties will function on a first-come-first-served basis with the oldest messages being presented first.

5.2.2.1 Exemplar Prioritize Process Logic

The chief process of Prioritize is to determine, based on metadata and context data, the relative importance of messages in queue. This dynamic prioritizing determines the order in which the scheduling process will select messages for analysis and presentation. An example of a processing logic is given in Figure 12-9.

The prioritize message output is an ordering of the messages in the queue. This relative priority determines the order in which messages will be processed by the Scheduling layer. In addition, the dynamic priority order index is published in the message status information so that applications may read this information and act on it if desired (e.g., if message index is high then perhaps the message should not be presented).

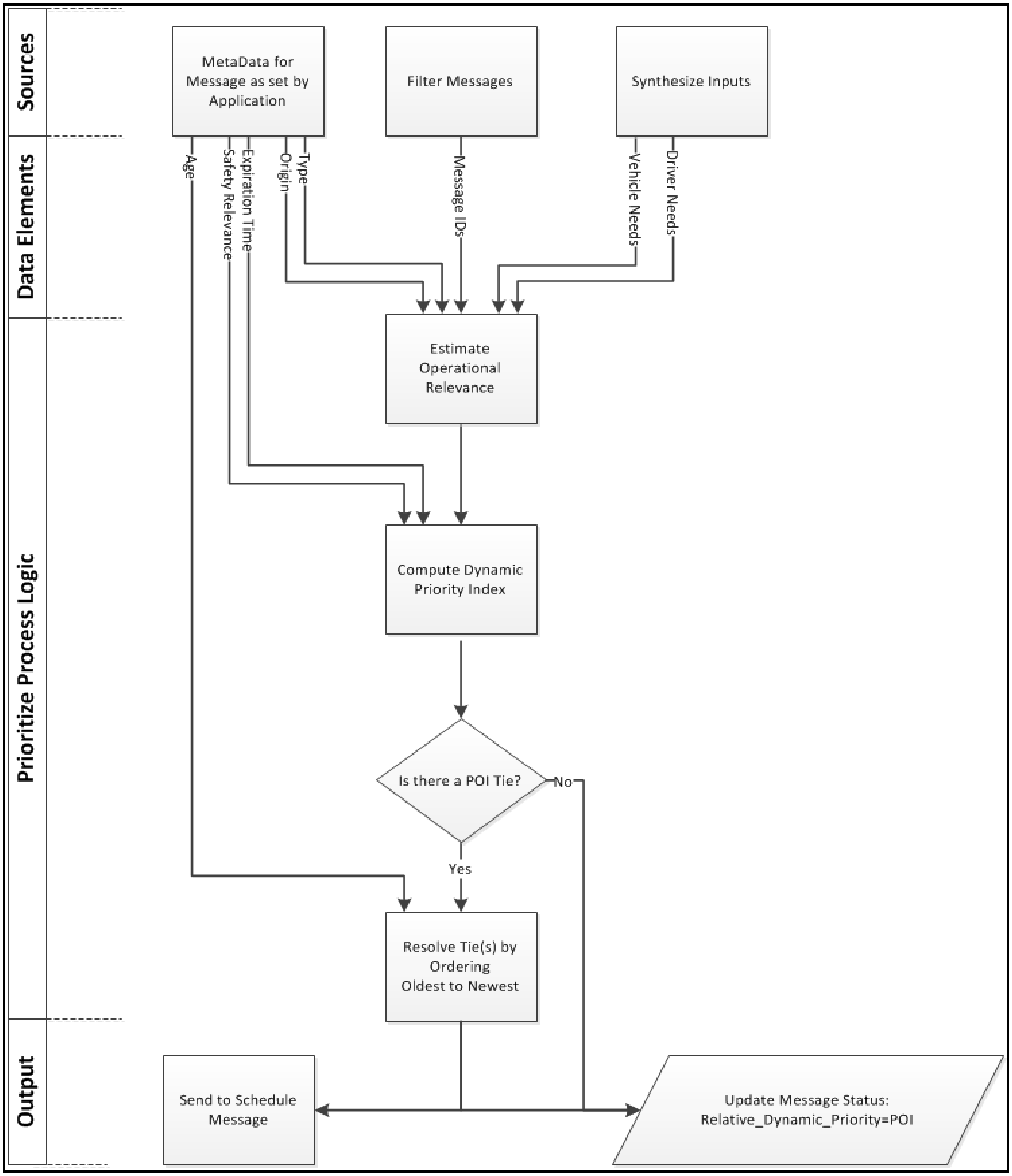

Figure 12-9. Example of a Prioritize process applied to messages that are intended for the driver.

5.2.2.2 Additional Discussion of Prioritize Process

Although presented simplistically, dynamically prioritizing a message is actually a rather complex endeavor. In Figure 12-9, the Estimate Operational Relevance process is the least understood, and yet one of the most important, component of the ordering. The ability to accurately and precisely compute a representation of relevance will require a thorough understanding of how the needs of the driver and vehicle map to the message type and origin. Determination of these relationships is dependent on some system-specific details, such as the ways in which driver and vehicle needs can be measured and represented. Ultimately, researchers and developers will need to create a strategy that links specific message types (which need to be defined) to specific needs (which also need to be defined).

There is also some question as to validity of the SAE priority index in this untested real-time application. While the method has face-validity, there may be differences in the real-time application that are not considered by the standard. For example, the real-time system has the ability to compute a continuous measure of Time Frame. Perhaps it would be better to compare priority on this continuous measure instead of lumping time into the four distinct buckets. A similar argument may be made for Operational Relevance, which may have more than three levels and perhaps be translated into a continuous measure (e.g., percent relevant) to permit finer-grained decisions. Safety Relevance could have more than three levels, as well, and perhaps even be set in real-time, based on specific conditions. It could be useful for non-imminent safety applications that may have a varying level of safety relevance depending on, for example, the roadway temperature and humidity in a slippery road application.

There are some scenarios that provide an argument to suggest that more complete models should be investigated. For example, research has demonstrated that occurrence of multiple imminent safety warnings is unlikely (Sayer et al., 2011). However, with the proliferation of additional collision avoidance applications in a CV deployment, the likelihood of simultaneous warnings will increase; particularly during evasive maneuvers when several different warning thresholds may be surpassed. There are indications that presenting multiple imminent safety warnings may have benefits when the directionality of the threat is conveyed (Lerner et al., 2011). In such situations, however, there are questions about whether the SAE model would correctly prioritize the message since messages would likely have the same Priority Order Index value. Such fine-grain adjustments may not be necessary, however, as benefits of dynamically changing the ordering of imminent safety warning presentation based on roadway conditions has not been demonstrated (Ward & Rahman, 2013).

5.2.3 Schedule Message

Message scheduling is the next step after prioritizing. This process determines the timing of message presentation by managing message cadence, based on current context and available metadata. The process starts with the highest priority messages, which will generally be presented in the same sequential order of the queue and at a rate that allows the driver to remain focused on the primary task of driving.

In general, message scheduling is governed by analysis of recent messages presented to the driver. Conceptually, for any given message, there is a certain amount of time required for the driver to safely perceive the message, recognize its meaning, and perhaps execute and/or complete a response. This slack time is dependent on the way in which the message was displayed (e.g., modality and location) and the message/response complexity. Slack time also depends upon the additional time needed for the driver to return focus to the driving task prior to delivery of the next message.

High priority messages are relatively straightforward to schedule. In most instances, such imminent safety messages will simply pass straight through the scheduling process for immediate presentation to the driver. If multiple imminent safety messages are passed from the prioritize process within a short window, the scheduling process may delay presentation of the subsequent message. This would be done to ensure the highest priority message is not attenuated or masked, which would undermine message perception and/or recognition. Once any safety message has been presented, subsequent non-safety messages may be delayed for some time to allow the driver sufficient time to perform an evasive maneuver or other safety message response.

For most messages, scheduling is more focused on pacing the driver's interaction with the DVI. To mitigate distraction, as well as to ensure usability, it is important that drivers be provided with sufficient time to return their attention from processing a message to the task of safely driving before another message is presented. In general, messages should be scheduled with enough slack time to allow the driver to attend to driving before being enticed to distraction by another inappropriately timed message (Allen & Howe, 2013). In the context of solicited messages occurring during continuous DVI interaction, scheduling is relatively straightforward; an appropriate message is displayed immediately after the driver's input makes the request. Therefore, the driver's rate of system input largely determines the message scheduling.

Perhaps the most important and least understood message type to be scheduled is the unsolicited message. Unsolicited messages are traditionally related to the vehicle diagnostic systems; such as low fuel and engine maintenance indicators. These messages are generally rare and benign; they often require no immediate action; and are displayed in locations reserved for that information. They can be readily ignored by drivers in the near term, but should eventually be noticed. Connectivity is bringing about a number of new applications that may produce a variety of new unsolicited messages, such as traffic delay ahead, appointment reminders, and in-vehicle signs. Such applications, which can provide safety and non-safety information, are generally lower priority but can be highly desirable.

The advantage of a low-priority message is the inherent flexibility of message timing. Generally, such messages can be delayed until the driver has sufficient available resources to safely respond. In some cases, a complex message (such as a video-message) could be delayed for long durations (e.g., until the vehicle is at a complete stop and perhaps even with the gear selector in park).

When the message scheduler sets message delivery, it does so based on some indication from the message's metadata about the typical processing time a driver will need to comprehend and act on the message. This assessment can be used to ensure that no potentially disruptive message is sent to the driver while the previous message awaits a driver response. For example, auditory messages take time to play to completion, and if they are complicated verbal messages, they could likely take more cognitive processing time before an action is taken. It is important that the driver not be sent another message while digesting the preceding message. The message scheduler makes this determination before transmitting the next message to the Manage Presentation process.

Message integration is supported by these scheduling functions to ensure that safety critical messages are dispatched quickly to the driver, while other messages are timed according to their relative importance and the driver's ability to safely receive a message.

5.2.3.1 Exemplar Schedule Process Logic

The chief process of Schedule is to determine (based on metadata, priority data, and presentation data) when to present the next message in the queue. This process is accomplished by analyzing each message in order, determining if a compatible DVI is available, adding slack time if necessary, and submitting the message for presentation when appropriate. An example of this schedule process logic is provided in Figure 12-10.

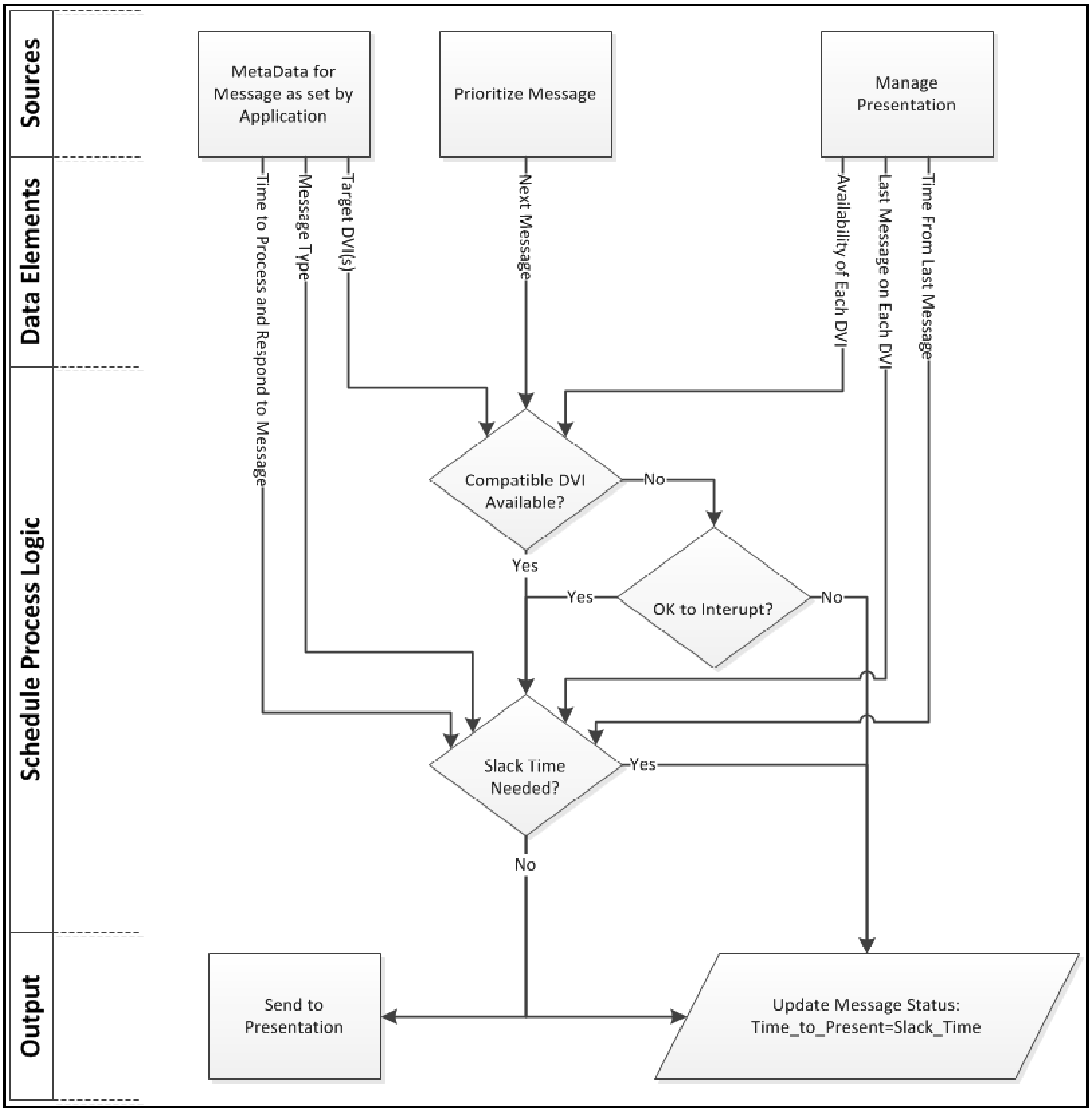

Figure 12-10. Example of a Schedule process applied to messages that are intended for the driver.

The primary schedule output is a decision on when to present the next message. Once an accepted message has been scheduled, it is forwarded to the presentation layer for immediate presentation. This layer does not block a message, but rather routes it to its intended interface. When a message is forwarded, the Message Status is updated to indicate a Time_To_Present of zero. When a message is delayed, it is scheduled for the next available slot and the Time_To_Present is populated with the estimated presentation time, based on information from the Presentation Layer. This information may be used by the application, which can choose to act on the content if desired (e.g., retract the message if it will not tolerate message delay).

5.2.4 Additional Considerations of the Scheduling Process

Portions of the Scheduling Process, such as waiting for the slack time to pass, provide explicit methods for controlling message cadence. However, the process as described above also has an implicit bottleneck for the rate at which messages may be presented. More specifically, the scheduling process is designed such that it assesses each message in order. This assessment can be made very quickly, perhaps faster than applications submit messages. As such, it is certainly possible for multiple messages to be presented over a short time period, and perhaps distributed to several different DVIs.

Consider this multi-message context in which several ordered messages in the priority queue await scheduling. The scheduler analyzes message “1” and sends it to visual DVI “A”. This first message expects the user interaction and remains on the visual DVI indefinitely awaiting input; however, the driver does not respond to the message. Message “2”, which requires access to DVI “A” for visual display and DVI “B” for auditory display, is processed next. Since DVI “A” is locked for use by Message “1”, Message “2” is delayed. While message “2” is delayed, there are two possible alternatives for processing Message “3”, which is an auditory only message seeking the use of DVI “B”.

- Block Message “3” from using DVI “B” since Message “2” requires both DVIs and DVI “A” is locked. This ensures the priority order is maintained; however, it creates a bottleneck for messages since both DVI “A” and “B” are blocked (even though DVI “B” is not actually in use).
- Allow Message “3” to surpass Message “2” and access DVI “B”. This allows more messages to be delivered; however, it results in a priority change that is not controlled by the prioritize process. Furthermore, there is a risk that Message “3” will tie up the DVI “B” after message “1” has cleared from DVI “A”. This results in additional delay for Message “2”, which could be compounded by additional single-DVI messages surpassing Message “2” and locking either DVI.

The impact of this bottleneck depends on the breadth of the system, the design and allocation of the DVIs, and the frequency of messages. The issue can be mitigated with careful design that minimizes the number of multi-DVI applications to a limited set (i.e., safety critical messages). In addition, this issue can be addressed in some instances by allowing messages to either interrupt or to share the DVI. Additional discussion on the topic of interruption and DVI sharing is provided in a special section later in this tutorial.

5.3 Manage Presentation

Beyond managing the flow of message information to a driver, it is also important to recognize that this information may be presented on various visual displays, played through the vehicle’s audio system, or delivered as a haptic signal through the seat, steering column, or other vehicle component. Information may also be relayed to the driver over a period of time, involving multiple related messages to fulfill a prior request (e.g., multi-screen messages displaying a series of traffic advisories up ahead) or interactive procedures to accomplish other goals (e.g., interactive toll payment screens that provide several payment options). Such operations might be vulnerable to disruption if unsolicited messages are allowed to interrupt the operation before it is completed. The Manage Presentation task monitors and publishes display status information to the Message Management process to permit decisions about when to schedule messages based on DVI availability.

The Presentation Management process accepts messages once they have been cleared for delivery by the Manage Messages process. Using the message metadata, the Presentation Management process publishes information about DVI availability, based on the applications and messages that are, and have recently been, displayed. For example, if the current message on a DVI is a multi-step process in which the user will have an ongoing interaction, the display will become unavailable to other applications (with the exception of a high priority, interrupting message).

A simple example of this is an internet radio application, which may consume an entire display with status information (station, artist, song, etc.) for an indefinite amount of time. The time for which an application has access to a display is based on the metadata; however, the presentation process is responsible for locking out the display, based on this information.

In addition to publishing DVI-related data, the Presentation Management process also distributes content to the vehicle's available displays; with the intent of creating a seamless user experience while enhancing driving safety, utility, and enjoyment. Message routing is determined by the message metadata, which includes elements about which DVI the message may be presented on. As discussed in the metadata section, the DVI has provisions for a single message that must use one or more DVIs as well as provisions that allow a flexible message to present on one of several DVIs, depending on availability.

5.3.1 Exemplar Presentation Process Logic

The chief purpose of the Presentation Process (Figure 12-11) is to determine, based on metadata and schedule requests, what message to render, and on what DVI to render it. The process then forwards the message to the DVI, keeps track of the DVI availability and publishes it to other processes.

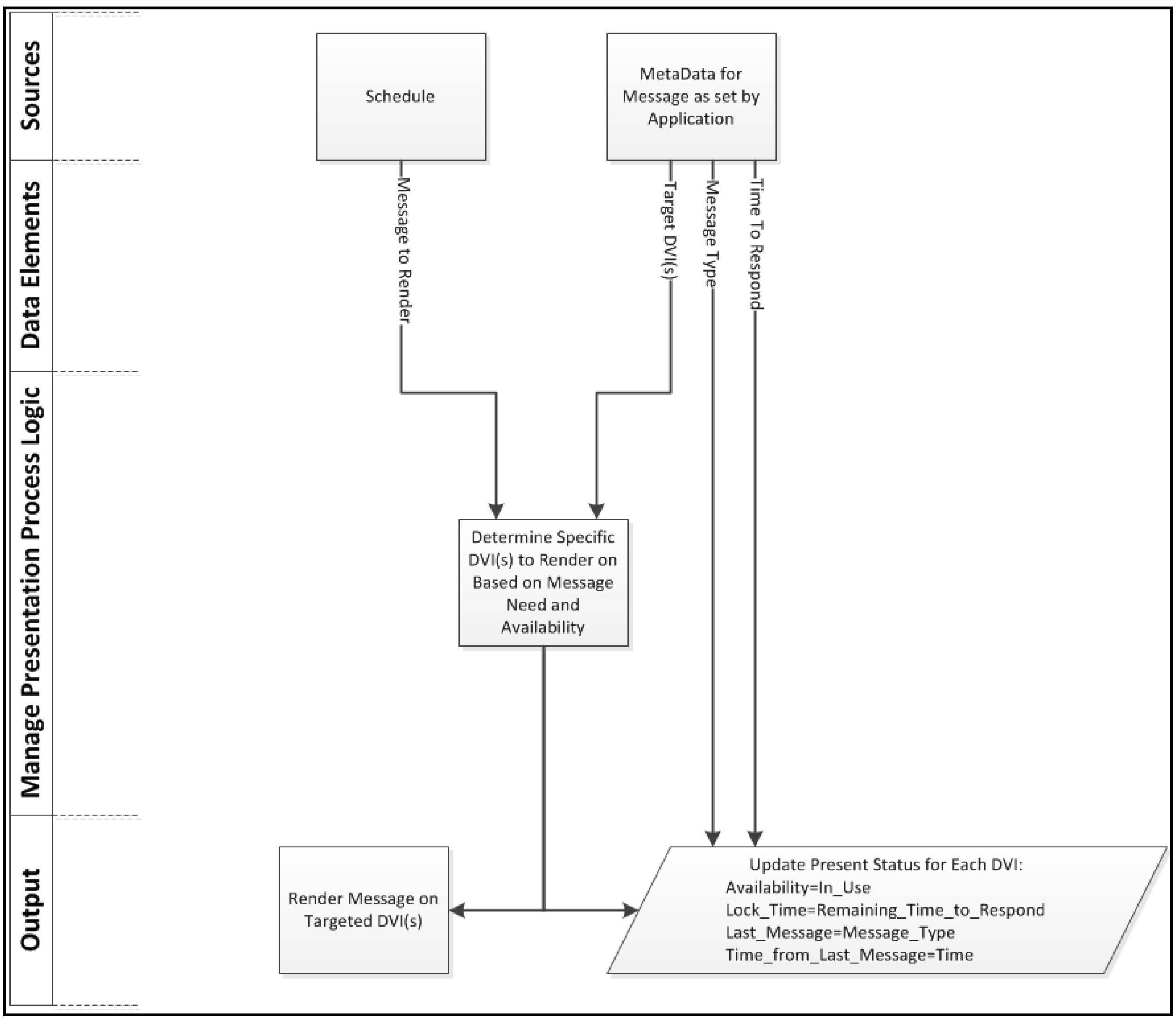

Figure 12-11. Example of a Presentation process.

The presentation process output is a rendering of the desired message on the appropriate DVI. When this rendering occurs, information for each DVI is published about Availability_Last_Message, and Time_From_Last_Message. These published values are used by the filter and scheduling processes to determine whether the resources are available to present the information, and to determine when it is appropriate to present the next message, based on the type and timing of the last message presented.

6 Additional Considerations for the System

The following section provides an overview of a few additional areas that should be considered when developing a Dynamic Integrator. This content does not necessarily map to any one specific process, but rather provides some important information that should be considered in light of a specific implementation.

6.1 Message Interruptions and DVI Sharing Between Messages

As alluded to a few times throughout this tutorial, it is possible for multiple messages to be presented at the same time. The decision to present multiple messages is made by the Dynamic Integrator and is based on the metadata and the context/status information published by the Synthesize Inputs and presentation layers. There are three ways in which multiple messages can be presented:

1. Multiple messages may be presented across different DVIs; one message per DVI.
2. A higher-priority message may interrupt a lower priority message on the same DVI.
3. Multiple messages may share a single DVI.

In the first case, designers need to ensure that metadata is configured such that compatible messages may be readily permitted for display at the same time, based on their DVI assignments. For example, it is likely acceptable for a simple icon on the dash regarding the need for an upcoming oil change to be presented at the same time as an in-vehicle sign on a center stack display. On the contrary, it may be confusing, and possibly more distracting, if a voice-based auditory message about slick roads is presented at nearly the same time as a visual message about an upcoming dining opportunity. The ability to display multiple messages on different DVIs is readily supported by the architecture. With thoughtful design, it should be feasible to designate DVIs for particular types of information to facilitate a consistent mental model for the driver, as well as limit the likelihood that two messages will both need a DVI at the same time (e.g., designate one specific display for short-duration messages so that long interactions do not block access).

While interruptions should be avoided in most cases, it may be reasonable to interrupt a message when critical information needs to be provided. The appropriate example is during the execution of a collision avoidance warning, which may need to interrupt in order to provide sufficient time for the driver to execute a successful evasive maneuver.

Interruptions, however, are not as simple as taking control over a given DVI in the context of a collision warning or other high-priority message. With a limited number of DVIs and a potentially large number of applications, it may be necessary to allow medium, and perhaps even lower, priority messages to interrupt a message from an application. For example, consider the case wherein a central DVI is displaying status information for an internet radio station (e.g., artist name, song name, etc.). When the driver executes the internet radio application, they are likely to leave the status content on the display, rather than return to a home screen where other content may be readily displayed. Although the driver opted to leave the status screen active, s/he may not be opposed to, and indeed may desire, the display of other relevant information. The metadata (such as the message response time element) may be used to control these low-level interruptions; however, caution should be exercised to ensure the architecture supports this design without unintended consequences and in a manner that does not distract or annoy the driver.

In some cases, it may be best to interrupt the message and consume the entire display (e.g., for a safety message). In these instances, the initial application message should be interrupted to convey the high-priority message in a salient fashion; this will maximize the opportunity for the driver to perceive, recognize, and respond appropriately. The interrupted application should simply pause until the interruption has been completed (and any slack time has elapsed as controlled by the schedule process; Allen & Howe, 2013). Research has shown that interruption strategy can impact driver performance (Holmes et al., 2013). Using partial-screen interruptions (in which the interruption is overlaid on the original content with the original content in the background) may improve the driver's ability to re-engage in the original task after the interruption is complete. When feasible, it may also be better to interrupt using a different modality (i.e., auditory message when the driver is performing a visual task; Holmes et al., 2013).

In the majority of situations, it may be more appropriate to identify methods for sharing the display surface real estate between multiple messages. Consider a display that is showing a map for a dynamic routing application. A small segment of this display may permit additional messages to be displayed in parallel. For example, a small display segment in the upper-left corner may allow simultaneous display of in-vehicle signage, such as the current speed limit or upcoming lane closure. Such multi-message DVI capabilities will need to be carefully designed and tested to ensure driver performance is not negatively impacted. Each layer of the integration architecture will need to be designed to use the shared DVI in a logical and user-accepted fashion.

6.2 Message Delivery During Driving

Not only is it important that a message be within the capacity of a driver to process and to respond to, but it is also important that an additional evaluation be performed to determine how a message's delivery will impact the driver's executive processes. This goes beyond the matter of one message interrupting another, by instead focusing on the interruption any message creates when it is presented during the primary task of driving.

Even if s/he is not performing secondary tasks, the driver is always multitasking when they drive (e.g., managing the scan of the roadway view, the control of the vehicle's lateral position, and its longitudinal speed and separation from other vehicles). Thus, it is important for the Manage Messages process to have rules governing interruption of the driver and their focus on driving though message delivery.

This is an emerging research domain as it relates to drivers. However, in other domains, such as aviation and human-computer-interaction, the management of interruptions has proven to be critical to operator performance. Indeed, some of what is known today from these fields can likely be applied to the development of Dynamic Integrators. Key resources may include: Latorella's Interruption Management Stage Model (cf., McFarlane & Latorella, 2002), as well as model-driven work like that by Trafton et al., (2003) in which the goal-activation model (developed by Altmann and Trafton; 2002) was used, and the Salvucci and Taatgen (2008) "Threaded Cognition Model." The notion underlying the Altmann and Trafton (2002) goal-activation model is that goals (the intention to perform some action in the future) are central to the way that people guide their behavior, the way they process interruptions, and the way they resume tasks. To the extent that a model can account for how a goal is affected upon message delivery and the way that it is retrieved when a task is resumed (after it has been interrupted), it may provide a way to predict behavior in the context of multitasking in general and in the context of driver distraction in particular (Angell et al, 2010). Such a model may provide guidance for constructing part of the "Manage" process.

Another interesting aspect of the goal-activation model is that it predicts that an interrupted driver (who has been diverted from the driving task for a certain period, perhaps a few seconds) must have "access to" or "be in the presence of" contextual cues in order to be able to return to the primary task after an interruption or secondary task (Angell et al., 2010). In CVs, it will be important to identify and separate messages that divert attention away from driving from those that direct attention to the roadway and safety-relevant events. Some CV cues may themselves actually serve as contextual cues that remind the driver to focus again on the driving task (and hence, supporting and facilitating the driver's attentional focus by essentially "strengthening" the activation of goals that ideally would be in working memory).

6.3 Assumptions and Limitations

The Dynamic Integration architecture makes many assumptions about our understanding of the driver and a future vehicle environment in which traditional and CV application messages are to be managed to provide a safe and enriched user experience. This architecture is offered as a starting place for designers to leverage while prototype integrators are developed. Ongoing research and development, internal and external to the HFCV program, will allow for the refinement of this architecture over time, reducing the present assumptions discussed in the following paragraphs.

The Synthesize Inputs process has been discussed as a method for assessing the driver's ability to safely receive messages; which can be represented simply as estimating driver workload. This workload can be estimated using relatively basic techniques today (e.g., workload is lower while the vehicle is static than while driving in an urban environment). These basic techniques still provide a powerful metric with which message handling decisions may be made. Moving forward, more advanced models (which may move toward a comprehensive estimate of workload across multiple resources) could provide the ability to more accurately determine when and how to present messages. While such theoretical models have been discussed over the last 20 years, they are not sufficiently mature to deploy within an integrator. More applied research is required to understand how workload can be estimated using the available real-time data sources and how such workload estimates correlate to safety risk.

The Manage Messages process is predicated on the assumption that all applications will route messages through a centralized gate-keeping process. In present vehicles, displays are often directly connected to specific application processors that do not share information with other processors. These existing architectures do not lend themselves to an integrated DVI and will need to be updated to enable the vision described herein. Furthermore, carry-in and other aftermarket devices such as Smart Phones provide an illustration of the difficulty of integrating all CV applications. For the purpose of this architecture, it has been assumed that such carry-in devices have a handshake and become part of the integrated system; however, it should be acknowledged and considered throughout design that this assumption may be violated.

The Manage Messages process also assumes that each message is accompanied by metadata that describes important attributes of the message to permit decisions regarding filtering, prioritizing, and scheduling; this allows comprehensive message arbitration. Thus far, some existing knowledge has been provided to inform portions of the metadata; however, much of the suggested content was derived from engineering experts rather than arrived at from empirical research. Such additional research will be required to validate the metadata's relationship to the decisions predicated, and, in some instances, this may even be necessary on each vehicle platform due to the differences in applications and display technologies.

The assumption of standardized metadata is particularly important in the surfacing model in which third-party vendors deploy applications on vehicle platforms; rather than on the integrated system or through a carry-in device. The third party must adhere to the systems standards, otherwise undesirable system behavior could result. Specifically, problems could occur if third-party vendors used metadata to improperly boost their applications' messages. As such, it may be necessary that administrative controls are put in place so applications have to undergo a validation process before they are allowed to reside on the vehicle.

It is also assumed that these metadata will be quantified in a systematic and consistent manner across all CV applications that transmit such messages. Such consistency suggests the development of governance strategies, and perhaps qualification/certification test methods, to set each metadata parameter. For example, the current priority assignments may be based on the ISO and SAE standards; however, these standards rely heavily on expert opinion. Perhaps more objective methods leveraging user testing would provide values that result in better message arbitration performance, particularly for non-imminent warnings in which baseline priority will often appear equivalent.

The Manage Presentation process proposes an architecture in which multiple display resources are shared among CV and non-CV applications. These multiple displays will each have certain advantages relative to the messages. For example, some displays may be better located and/or formatted for specific types of content. It is assumed that application metadata will allow the Manage Presentation process to target the appropriate display; however, there are knowledge gaps in which display technologies are best suited to each type of message content.

Lastly, the architecture presented here is focused on information flow and how to address a driver's processing bandwidth. It should be recognized that there are other integration issues not addressed in the architecture, which can arise in an environment where multiple message sources act independently. For example, systems that produce warning notifications often emit audio warnings accompanied by flashing displays. While efforts are made to ensure these warnings are distinctive, there is no guideline or standard in place to prevent a curve speed warning, for example, from producing a sound similar to a forward collision warning or a cell phone notification. This kind of integration is outside of the tutorial scope; however, it should be addressed by designers and may lend itself to some industry standardization.

6.4 Discussion of Possible Future Research

Overall, future research should work to refine this proposed Integration Architecture based on feedback from a broad stakeholder community. It is critical to understand how this tutorial will be applied by the community, which elements are helpful for developing integration strategies, which elements can be improved, and how, and what, additional information would be helpful in future revisions. Presuming acceptance from the community, this research should lead to a refined version of the architecture that can be broadly disseminated with the intent of providing a foundation on which developers can build their integration strategy, helping to ensure critical design decisions are considered.

Throughout this tutorial, particularly within sections covering additional considerations, the need for future research efforts within specific areas of the architecture was established. Although details of these needs are best left within the context of those discussions, key future research areas are briefly summarized in the sections below.

6.4.1 Applications, Messages, and Metadata

The architecture presumes that applications are refined and adhere to a set of prescribed rules. This implies that applications are either developed by OEMs or are carefully reviewed by OEMs through a certification process. However, there is a need for OEMs to allow more open-access to applications, whether installed on the vehicle from third party vendors or though integration of a carry-in device (e.g., smart phone). The ability to permit this open application architecture deserves targeted research to investigate the efficacy of this approach as part of an integrated system.

More open systems will require robust standards to ensure expected Dynamic Integrator operation. For example, it is important that all applications use the same objective method to measure the metadata element that defines the expected time required for driver response. If this measure is not correct, the scheduling layer will make inappropriate decisions, perhaps resulting in distraction from a rapid message delivery cadence.

Such standards will define what applications are permitted on the vehicle, how the applications share information, what metadata is needed, how should such metadata be structured, how to objectively and reliably compute metadata, and certification testing requirements and methods. Such standards will ensure that messages are appropriately arbitrated by the Dynamic Integrator.

6.4.2 Synthesize Inputs

Successful application of the Dynamic Integrator is predicated on an effective prediction of the driver's ability to safely receive, and appropriately respond to, messages. Workload appears to be the most mature construct for evaluating the driver's capacity; however, the measurement and application of workload in real-time is largely untested. Specifically, which measures of the driver and vehicle can be used to objectively measure workload? Is the method of workload assessment valid in its ability to predict capacity? Is it sufficient to assess workload along one dimension, or does workload within each of the driver's attentional resources channels need to be considered? How many levels of workload are required, or should workload be measured along a continuous scale? It is critical that links between the driver's real-time workload and their ability to safely receive messages is established?

Next, the Synthesize Inputs layer must be able to evaluate the requirements of a given message, based on its metadata, with the real-time workload to determine whether or not delivery of the message is permissible. This means the workload assessment of the message must be directly additive to the real-time workload. This implies a consistent scale and a reliable method for computing workload demand estimates for every message.

In addition, the provision for allowing user configurations to affect the Dynamic Integrator needs to be researched. Specifically, what elements of configuration will improve driver performance and acceptance? Should drivers only be permitted to make selections that decrease potential demand, or should they be allowed to select configurations that could increase the additional demands created by the CV system?

Finally, the proposed architecture also has provisions for systems that attempt to predict driver and vehicle needs in order to influence the message's operational relevance. Measures and methods for evaluating these needs are largely undeveloped and untested. The ability to predict such needs will likely improve the Dynamic Integrator's ability to provide the driver with the most context-relevant information; however, additional research is clearly required to evaluate the efficacy of such an approach.

6.4.3 Manage Messages

The Manage Messages process is made up of the three sub-processes, all of which require additional research. The filter process appears to be an effective way to reduce distraction while still allowing the vehicle to have a variety of CV applications. However, the methods to execute filtering effectively are largely undefined. For example, at what levels of workload should filtering be applied and to which types of messages? Is it better for the system to completely remove applications from the interface, or should inappropriate options be grayed-out or otherwise indicated as unavailable to the user? Will drivers accept having information filtered out? How can filtering be best communicated to the driver to ensure expectations are not violated (e.g., a desired application that is being relied on does not provide the desired message)?

Future research questions for the Prioritize process focus on the mechanism applied for objectively setting relative priority in real-time. It was suggested that existing strategies, such as the SAE standard, be augmented to function in real-time. However, there is little evidence to support the SAE prioritization method working effectively in a real-time context. Furthermore, questions quickly surface about whether the SAE standard has sufficient resolution for the attributes that impact the priority index (e.g., safety relevance, time frame, etc.) to effectively arbitrate messages in a CV environment. It is possible that such attributes should be measured over a number of additional levels or perhaps on a continuous basis, rather than using the lookup table as presently specified. It may also be that either different or additional attributes are required to accurately set message priority.

At present, it appears reasonable to set safety-relevance and time-criticality based on the basic premise of the SAE standard. However, objectively setting a value for operational relevance in real-time does not appear trivial and will likely depend heavily on information collected during the Synthesize Inputs process. It will be important to research, develop, and test methods for assessing operational relevance in a manner that allows accurate message arbitration, given the current context data.

The last sub-processes within Manage Messages is Scheduling. Although some existing research is available, there are unknowns with regard to the appropriate message cadence as a function of the message type. Additional research to further understand when it is appropriate to interrupt messages and how the driver will respond to interruptions is both appropriate and valuable. This question is of particularly interest in the context of unsolicited messages and how often they should be presented. There are also some rather complex questions, related to interruptions, when considering applications that subsume a display for long period of times, possibly resulting in a message backlog if they cannot be scheduled.

6.4.4 Manage Presentation

The final process, Manage Presentation, also gives rise to a number of research questions. One particularly interesting area focuses on the impact of message allocation to the DVIs. Specifically, are there benefits to allocating each display to specific types of information? Are these benefits large enough to promote additional dedicated DVIs within the vehicle (for example, allocating one display for driving related information while another only displays non-driving related information)? Alternatively, perhaps a better display allocation is based on the message type (solicited versus unsolicited).

Continuing the multiple DVI discussion, what is the impact of presenting multiple applications across different displays at the same time? Are there certain display types and/or locations that can be readily ignored by the driver? How can such displays be used as part of the priority process to allow benign messages to be readily presented under the presumption that they will be inherently noticed when the driver has spare capacity?

What are the best strategies for presenting multiple messages—particularly in the context of interruptions? Should overlays or split screens be used to share a DVI between two applications? Can two messages be presented if they are using completely different modalities?

Finally, how should the presentation strategy consider passengers in the vehicle? The architecture presented is focused on the driver; however, passengers often use the in-vehicle displays and may want access to (and indeed can safely use) additional functionalities. Are there reasonable methods to allow presentation of additional content to passengers without impacting the driver's abilities?

7 Conclusions

The key function of a successful integration architecture is to control the flow of information to a driver so that important (i.e., urgent, critical, and safety relevant) information is presented in a manner that best ensures the driver will be able to react to this information in an effective way. In the architecture presented, this is accomplished by Filtering, Prioritizing, and Scheduling messages to account for the driver's inferred workload (in the context measured by the Synthesize and Present processes).

In this framework, the driver is conceived as a limited-bandwidth information processor, whose capacity shrinks and expands based on contextual factors. Tracking this capacity is the responsibility of the Synthesize Inputs process, which informs other processes within the Manage Messages how to structure relevant information flow in a manner that does not exceed the driver's current bandwidth. As with any system that must deal with processing bottlenecks, Message Management employs a prioritized queue to hold messages until they can be safely processed by the driver (or until their relevance or utility declines). Finally, at the last stage of integration, there is a Manage Presentation process that is responsible for distributing messages to the appropriate displays.

The successful implementation of an integration architecture will ultimately be determined by vehicle and device manufacturers. Rudiments of this approach can be seen in the current integration mechanisms on modern vehicles. For example, cell phone integration is usually accomplished through a Bluetooth interface that permits the vehicle's on-board entertainment systems to control basic functions of the telephone; iPods are controlled through custom or USB-based connectors that allow in-vehicle controls to directly manipulate the device. Thus, a basic form of gatekeeping is currently provided that regulates access and control to the phone or music player. The current architecture proposes that message metadata and integration processes might be developed to permit more sophisticated regulation of information than is currently available. This can only occur if vehicle manufacturers and device manufacturers participate in a cooperative effort to establish standards.

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Tutorial 4: Heavy Vehicle Characteristics and Driving Environment Relevant to DVI Design[4]

This tutorial reviews four issues relevant to heavy trucks and transit bus crash warning system DVI design: vehicle characteristics; operational considerations; crash data; and driver tasks and workload. The tutorial provides general information that may be useful to designers developing CWS DVIs. The following discussion is limited to tractor semi-trailer heavy trucks and transit buses.

Vehicle Characteristics

The basic physical characteristics of heavy vehicles have an impact on drivers' needs and requirements for DVI information. Accordingly, the physical dimensions, stopping distances, and drivers' working areas of heavy trucks and transit buses are reviewed in this section of this tutorial.

Vehicle Physical Dimensions

A typical combination interstate tractor-semitrailer is 13.5 feet high, 8.5 feet wide, and between 68.5 and 73.5 feet in total length. The typical tractor-semitrailer has 5 axles and a federally-specified maximum gross vehicle weight of 80,000 lbs. (although individual states may allow greater gross vehicle weights). Figure 12-12 presents two common heavy truck configurations. The tractor semitrailer configuration on the left (showing a tractor pulling a single van/box trailer) is the most common configuration and is used extensively for long and short hauls in all urban and rural areas to carry and distribute all types of materials, commodities, and goods.

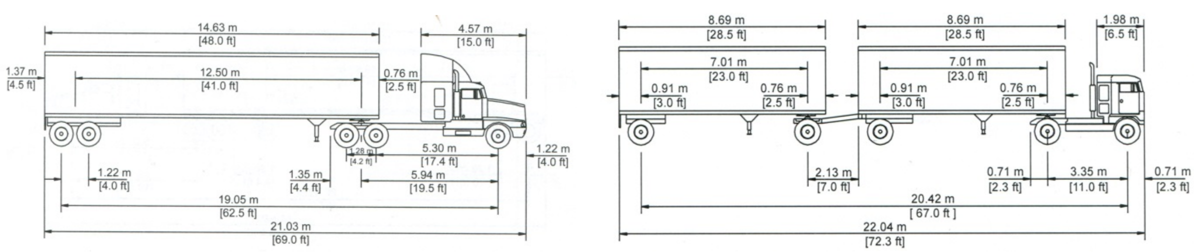

Figure 12-12. Example tractor-semitrailer configurations (from AASHTO, 2011, A policy on geometric design of highways and streets, Washington, DC. Used with permission).

The two most common city transit bus configurations are the 40-foot, two-axle city transit bus and the 60-foot, three-axle articulated bus depicted in Figure 12-13.

[4] Tutorial 4 is an updated version of Tutorial 3: Factors to Consider in Designing CWS DVIs for Large Vehicles from an earlier guidelines document:

Campbell, J. L., Richard, C. M., Brown, J. L., & McCallum, M. (2007). *Crash warning system interfaces: Human factors insights and lessons learned* (Final report. Report No. DOT HS 810 697). Washington, DC: National Highway Traffic Safety Administration.

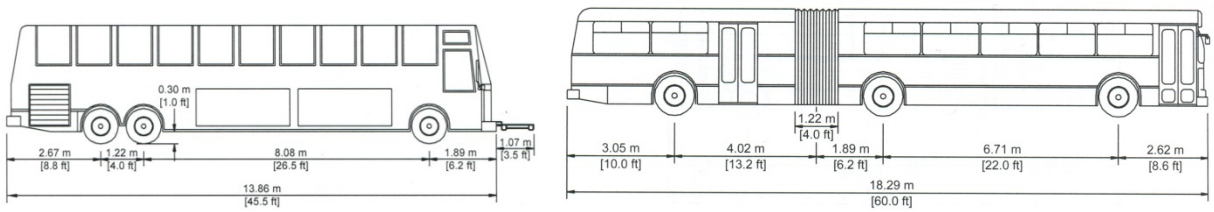

Figure 12-13. Example city transit bus configurations (from AASHTO, 2011, A policy on geometric design of highways and streets, Washington, DC. Used with permission).

Driver Working Areas

One starting point in reviewing driver working areas is to consider the general layout of seating and controls. Because the visual, auditory, and haptic/tactile work environments in these working areas are critical in the selection and specification of CWS warnings, brief descriptions of these modality-specific working environments are provided below.

Visual Environments

There are visibility challenges that drivers of heavy trucks must cope with in order to continually monitor the surrounding traffic on the roadway. Blind spots around a typical heavy truck are depicted in Figure 12-14. Without the aid of mirrors (e.g., convex mirrors) the driver of a heavy-truck has no clear vantage point for seeing directly in front of the tractor. There are also blind spots to the left and right of the vehicle that are not symmetrical, and a blind spot extending out from the rear edge of the trailer. The shape of the blind spot to the right is different compared to the blind spot on the left. The extent to which visual blind spots can be attenuated through the use of fender-mounted mirrors is an important consideration. The usefulness of radar or video-based technological solutions for reducing blind-spot problems is inconclusive. In a small study (i.e., this study had 8 participants) that compared a set of Side Object Detection Systems (SODS), Mazzae and Garrott (1995) found that fender-mounted mirrors provided blind spot coverage superior to any other side object detection system that they tested. Fitch et al. (2011) reported on a field test of a camera-based system for providing side and rear blind-spot views to heavy truck drivers. Results indicated no significant differences in safety-critical event involvement; however, many drivers preferred the rear-facing camera view relative to the left or right side views.

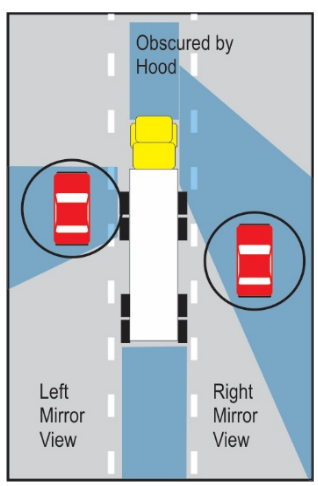

Figure 12-14. Depiction of heavy truck blind spots (adapted from FMCSA, n.d.).

Transit bus drivers must also deal with blind spots. Figure 12-15 depicts generic blind spots for an unspecified bus, as adapted from Thorpe, Duggins, McNeil, and Mertz (2002). It should be noted that the general locations of the depicted blind spots in Figure 12-15 are influenced by cab design features like dash height, fare box location, and mirror locations, which may vary depending on bus design (e.g., low-floor, motor coach, articulated, etc.). One advantage that both heavy truck and transit bus drivers have in terms of their visual environment is that they sit higher than passenger car drivers. As a result, they can see farther when there are vertical sight restrictions, such as other vehicles or hillcrests. This may permit large vehicle drivers to see traffic conditions or hazards sooner and allow them to have more time to respond to those conditions.

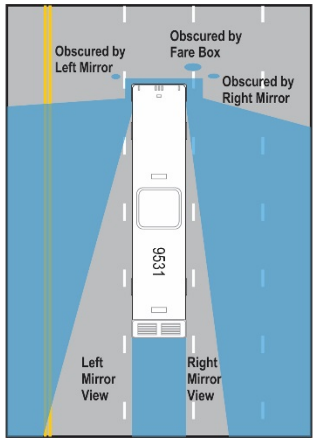

Figure 12-15. Depiction of typical transit bus blind spots (adapted from Thorpe, Duggins, McNeil, & Mertz, 2002).

Auditory Environments

Robinson et al. (1997) suggested the use of noise-sensing circuits to adjust alarm output levels as the truck cab noise level changes, thereby maintaining a desired signal-to-noise ratio (SNR). They also suggested lowering truck-cabin noise to an OSHA acceptable time wieghted average (TWA) level, which is 90 dBA for 8 hours. The lowering of cabin noise may help drivers detect external cues for train horns and emergency vehicle sirens. Fu et al. (2010) measured sound levels in a fleet of trucks and found that noise can reach levels of up to 97.5 dBA but TWA is well below the OSHA standard, ranging from 20 to 45 dBA (see topic *Design Guidance for Auditory Displays in Heavy Vehicles*).

Sources of noise in transit buses include the vehicle engine, air brakes, pneumatic doors, coin sorter, passengers, and surrounding traffic noise. Reinach and Everson (2001a) identified relatively high and variable levels of ambient noise in transit buses as a consideration in system design. Henrique and Zannin (2006) measured noise levels for a full fleet of urban buses in the city of Curitiba, Brazil and they found that most buses abided by the Brazilian Occupational Health Standard NHO-01 as their noise levels incident toward the driver were below 82 dBA, which classifies them as acceptable for long exposure without causing hearing damage. The buses did not comply with the Brazilian standard for ergonomics NR-17, however, because the internal noise of all measured buses was considered *uncomfortable* to drivers (i.e., > 65 dBA for 8 hours). The implication from these results is that the sounds levels in buses are not likely to contribute to occupational injury that is physiological (e.g., hearing damage from long term exposure) but long-term exposure may affect the well-being of drivers—the well-being of bus drivers is a long-standing issue with decades of research supporting the notion that there are many factors that have historically had negative impacts on bus driver mental health, in addition to their physiological health (see Tse, Flin, & Mearns, 2006). This may have implications for the volume and rate of occurrence of auditory messages and warnings.

Haptic/Tactile Environments

The truck cab haptic/tactile environment is of interest in the present review because heavy truck collision warnings might potentially employ some form of haptic or tactile signal. Jiang, Streit, and El-Gindy (2001) reviewed heavy truck ride comfort research and computer-based simulations of cab vibration. Their review shows that vehicle suspension is a very important factor in cab vibration. Since heavy truck handling and rollover characteristics are the primary concerns in suspension design, however, this leaves the cab suspension, seat suspension, and the seat cushion as components that can be modified to reduce driver vibration (e.g., seats that counteract vibration). Thus, haptic/tactile warnings should be designed with a clear understanding of the relationship between the design of the cab environment and the subsequent transmission of vibrations to the driver.

Reinach and Everson (2001a; 2001b) cite conditions of high vibration in transit buses in recommending that transit bus haptic displays must be capable of being presented, attended to, and understood under high vibration conditions. These authors specifically highlight the likely masking of haptic signals from the foot pedal and steering. Wang et al. (2003) reported that transit drivers were generally dismissive of haptic seat warnings, due to their periodic movement in the seat and "rear-end fatigue." On the other hand, bus drivers tended to like feedback about their lane position when the vibrations were delivered via the driver seat (Pessaro & Nostrand, 2011). In this specific case, the haptic seat display was part of a driver support system that had multiple messages that were redundant, and these other message sources were viewed as not useful, distracting, or, as in the case of steering wheel torque, an encumbrance to the driving task—this design case is discussed in greater detail in a later section in this tutorial on DVI considerations.

Operational Considerations

Three topics related to heavy truck and transit bus operations that are relevant to DVI design are the roadway environment, driver characteristics, and reactions by large vehicle drivers to early tests of collision warning systems. Each of these topics is briefly reviewed below.

Roadway Environment

Kiger et al. (1992) surveyed 55 heavy truck drivers to determine the relative perceived importance of a range of driving conditions to safety. Table 12-10 presents the subjective safety ratings of these factors as judged by the sampled drivers. As can be seen in the table, the order of relative importance was road traction, visibility, traffic density, roadway division, and lighting.

Table 12-10. Heavy-truck driving condition factor relative importance (from Kiger et al., 1992).

Driving Condition Factor	Levels	Relative Factor Importance
Road Traction	Good traction versus poor traction (slippery ice, heavy rain, mud, snow)	51.6%
Visibility	Good versus poor (e.g., foggy with visibility of barely one truck length ahead)	25.8%
Traffic Density	Light versus heavy	12.9%
Roadway Division	Divided versus undivided	6.5%
Lighting	Day (sunny) versus night (moonless)	3.2%

Transit buses operate in a highly “cluttered” roadway environment. Buses are most commonly operating in the curb lane with numerous small objects in the vicinity (e.g., pedestrians, cyclists, lamp posts, mailboxes, street signs). Transit operators often encounter drivers and pedestrians who carry out risky behavior at very close proximity to the bus. For example, it is not uncommon for vehicles to cut-off a bus only to immediately turn right (UC-PATH & CMURI, 2006).

Driver Characteristics

Both heavy truck and transit bus drivers are required to meet Federal Motor Carrier Safety Administration requirements for obtaining and maintaining a commercial driver’s license that is either Class A (any combination of vehicles with a GVWR of 26,000 or more pounds) or Class B (any single vehicle with a GVWR of 26,000 or more pounds). Drivers need additional CDL endorsements to operate special vehicle configurations (such as double, triple, or tanker trailers), haul hazardous material, or carry passengers. CDLs are issued with restrictions based on the equipment the driver uses to complete the CDL test in order to prevent unqualified drivers from operating specialized equipment. For instance, depending on the vehicle the driver used to complete the CDL test, restrictions may be placed on a CDL to prevent drivers from operating vehicles with air brakes or manual transmissions.

Physical requirements for obtaining a CDL include 20/40 corrected vision, a 70-degree field of vision in each eye, and normal red-green color discrimination. Commercial drivers are given a hearing test and required to hear a forced whisper in one ear that emanates from 5 feet away or greater, this is with or without a hearing aid. Drivers must have normal lung and cardiovascular health, no history of epilepsy or other disorders of consciousness, no uncontrolled medical conditions that could lead to a loss of control behind the wheel (e.g., uncontrolled sleep apneas or diabetes), and have normal use of their arms and legs. There is some speculation that truck drivers develop noise-induced hearing loss over time, however the evidence for these claims is inconclusive (see Heever & Roets, 2010; Karima et al., 2010)

Most commercial motor vehicle drivers are allowed by current hours of service (HOS) regulations to drive for 11 hours per day (Hours of Service of Drivers, 2011). Additionally over-the-road or long-haul drivers typically live and obtain their regular sleep inside their truck, sometimes for a month at a time (Bureau of Labor Statistics, 2014). One study of commercial driver fatigue identified that drivers averaged 5.5 hours of sleep per 24 h period (Blanco et al. 2009). Perhaps unsurprisingly, fatigue in the form of drowsiness has been identified as a safety concern in commercial vehicle operations.

Analyses of safety and work hours have identified an increase in safety-elevant driving events as hours spent working increase (Soccolich et al. 2011; Jovanis, Wu, & Chen, 2011). However, the relationship between operational safety and driving hours is not straightforward. Analyses of driver performance have identified beneficial effects from rest breaks during the work day as well as deleterious effects for non-driving work activities prior to driving (Soccolich et al., 2011). Additionally, issues such as obstructive sleep apneas (that can result in loss of consciousness or microsleep events while driving) are of greater prevalence in the commercial motor vehicle driving profession than in the general population and can be associated with safety decrements (Pack, Dinges, & Maislin, 2002). Thus, fatigue and fatigue mitigation is a perennial concern in the commercial vehicle operations domain.

Heavy-truck driver training is quite variable and typically governed by what trainers deem as adequate (Brock, McFann, Inderbitzen, & Bergoffen, 2007). There are no minimum training requirements for obtaining a commercial driver's license and there is a large amount of variability in the training programs that are available (Morgan et al., 2011). Comprehensive training programs are available. Professional Truck Driver Institute-certified courses include training in safe and advanced operations practices, including: visual search, speed and space management, night operation, extreme driving conditions, hazard perception, emergency maneuvers and skid avoidance, and skid control and recovery. PTDI certification requires 104 hours of classroom time and 44 hours per student of instructor-supervised driving (PTDI, 1999). Non-PTDI certified programs can display much more variability in the training provided to drivers (Morgan et al. 2011). Many of the larger carriers, however, do not require driver training for their entry-level drivers, rather, require minimum automobile driving experience levels (e.g. two years) and a "clean" driving record (Staplin, Lococo, Decina, & Bergoffen, 2004).

Most transit bus operators provide their drivers with classroom and behind-the-wheel instruction, and the training duration varies across operators by between two to eight weeks. Classroom training typically addresses rules and safety regulations, state and municipal driving regulations, and safe driving practices, which are established by the Department of Transportation and transit authorities. Transit drivers also receive training in reading bus schedules, determining fares, keeping records, and being courteous with passengers. Behind-the-wheel training typically begins on a closed-course where turning, backing up, and driving in narrow lanes is practiced. On-road training will follow the closed-course training and typically progresses from light to congested traffic conditions, followed by supervised driving on scheduled revenue routes.

Bus drivers in the United States tend to be older. In 2012, the bus driver workforce in the United States was approximately 558,000 drivers; 75 percent of the workforce was 45 or older, with a median age of 53.5, and 15 percent of the driver population 65 or older (United States Department of Labor, 2013). The older age demographic may be unique to the United States. Most bus drivers in the Republic of Germany retire at around age 50 and only 5 percent retire at 63 (Göbel, Springer, & Sherff, 1998). The early retirement of bus drivers in Germany may be a result of their assessment practices for determining whether or not to allow a driver to continue operating a bus. To operate a bus in Germany, drivers must submit a medical evaluation that proves their ability to cope with stress and that their faculties of orientation, concentration and attention and reaction are adequate. There is a considerable amount of research dating back to the 1950s that indicates a strong link between bus driving and decrements to physical and psychological health (see also Tse et al., 2006).

Driver Reactions to Early Tests of Collision Warning System Components

A few projects have included on-road assessments of collision warning systems technologies in buses and heavy trucks, although some have methodology issues that severely limit the usefulness of their results.

Heavy Trucks

Dinges et al. (2005) reported that the SafeTRAC lane departure system received ratings of modest favor by heavy truck drivers. One common comment by drivers was that the SafeTRAC auditory alarm was set too high and they wanted to be able to adjust it. The intense volume was a feature of the pilot study protocol rather than the technology. The negative reaction to the auditory alarm might have reduced overall driver acceptance of the system.

There is one research paper that suggests that the sound of auditory warnings may be distracting for experienced drivers. In a simulator study, experienced drivers responded to an emergency situation almost 2 full seconds slower when a *high urgency* alert sounded compared to a *low urgency* alert (Fagerlönn, 2011). The spectral and temporal parameters of the alerts were adjusted to create the two different levels of urgency. For example, the high urgency alert consisted of 8 discordant and loud (85 dBA) tone bursts with 100 ms inter-pulse intervals, whereas the low urgency alert consisted of 3 quieter (80 dBA) and harmonious tone bursts with 300 ms inter-pulse intervals. However, this study lacked a proper control group of inexperienced commercial drivers and should be interpreted with care.

Different presentation methods involving muting of secondary audio sources were evaluated for a FCW system for heavy trucks using a test track (Tidwell, Blanco, Trimble, Atwood, & Morgan, in press). The warning included a visual alert presented on the top edge of the instrument panel (within 15° of the forward line of sight). The warning sound (sound 8 from Kiefer et al., 1999) was presented in three conditions (with music that was immediately muted with alert issuance, muted 250 ms prior to alert issuance, or not muted) and compared against a no-alert baseline condition. The event used was the sudden braking of a lead vehicle in front of the participant in a heavy truck. The alert was presented at 87 dBA, with the music at 72 dBA and ambient noise of the truck cabin at 69 dBA. Results indicated that drivers in the preemptive muting condition and no-muting condition had a faster time for throttle release when compared to the baseline condition; however, no differences between conditions were identified for the time to apply the brakes. Approximately 47 percent of drivers looked to the ICW visual alert at some point during the event, however the majority (approximately 83%) of drivers' first response to the alert was to look toward the forward roadway. The majority of drivers in this study felt the size (72%), color (96%), image (88%), sound (92%), auditory duration (80%), and loudness (78%) were appropriate. These findings indicate that presenting a warning in a non-distracting fashion in a manner appropriate to the situation can assist with driver acceptance.

Transit Buses

UC PATH and CMURI (2004) reported the results of an 11-month pilot test of two transit buses equipped with prototype FCW and side collision warning (SCW) systems that included an integrated visual warning display. This system was operated by several dozen bus operators in the greater San Francisco Bay Area and Pittsburgh suburban and city areas. Contrary to some expectations, there were no reported negative reactions by passengers to this system and drivers' reactions were generally favorable. These researchers reported a substantial level of disagreement among drivers regarding the use of auditory warnings, which was notably not implemented in the pilot test. An additional finding of note concerned drivers' reported difficulty in viewing the pillar-mounted visual displays when driving into the sun, although this was also identified as a critical period when the system could provide significant benefit.

Pessaro and Nostrand (2011) evaluated a driver assistance system that was designed to provide warnings to bus drivers when they exceeded the boundaries of bus-only shoulder transit lanes. They surveyed twenty-five drivers on their use of the system. The majority of drivers indicated that they found some features of the system to be distracting and not helpful (e.g., the head-up display, steering wheel torque, and liquid crystal display that showed surrounding hazards), but many of them made positive responses to the boundary warnings provided through vibrations from the haptic seat. The vibrations occurred on the left and right of the seat pan depending on if the bus deviated over the fog line and toward traffic (left vibrations), or if the bus was driven off the road (right vibrations).

It is important to review a few rather important lessons learned from the deployment of the bus-only shoulder support system that was evaluated by Pessaro and Nostrand (2011). Two notable lessons-learned that may be relevant to interpreting the results are stated below:

- The use of the intended area (e.g., shoulders on specific areas of highway) within which the system was to provide assistance unexpectedly changed after the system was deployed. This change in bus driver use of these areas of shoulder resulted from other improvements to the road system that ameliorated the traffic jams that would have otherwise caused bus drivers to use the shoulders. When the traffic problem disappeared drivers no longer needed to use the shoulders.
- In addition, the use of the system was never fully evident. Drivers and trainers stated that they were uncertain of the value of the system. The system was originally designed to support snow plow operations. A lesson learned is that transit and snow plow operations are not the same.

Also relevant to interpreting the results is that starting with its inception in 1991, the amount of bus-only shoulder lanes in Minnesota increased by 10 to 30 miles per year up to almost 300 miles in 2006, and during that time there were only 20 crashes on the shoulder, which were mostly minor scrapes or mirror clips (Duoma, Poindexter, & Frooman, 2008).

Crash Data

The following sections discuss the distribution of crash types for heavy trucks and transit buses. Information about crash types is relevant to the driver's need for specific types of hazard information and – in turn – may be used to inform DVI design. In 2014 in the United States there were 10.8 million vehicles involved in motor vehicle crashes, 4.1 percent of these crashes involved a large truck and 0.6 percent involved a bus. Although large trucks were involved in 8.3 percent of all fatal crashes, the actual proportion of crashes that involved large vehicles was considerably smaller compared to passenger car and light truck crashes (39.8 and 38.2 percent, respectively). Overall, trucks are less likely to be in a fatal crash per mile driven than passenger cars; however, once a truck is involved in a crash, the outcome is more likely to include a fatality than when a passenger car is involved in a crash. In contrast, just 0.5 percent of the total bus crashes resulted in a fatality (i.e., specifically, there were 234 fatalities within the 69,000 total crashes that involved a bus; see NHTSA, 2014).

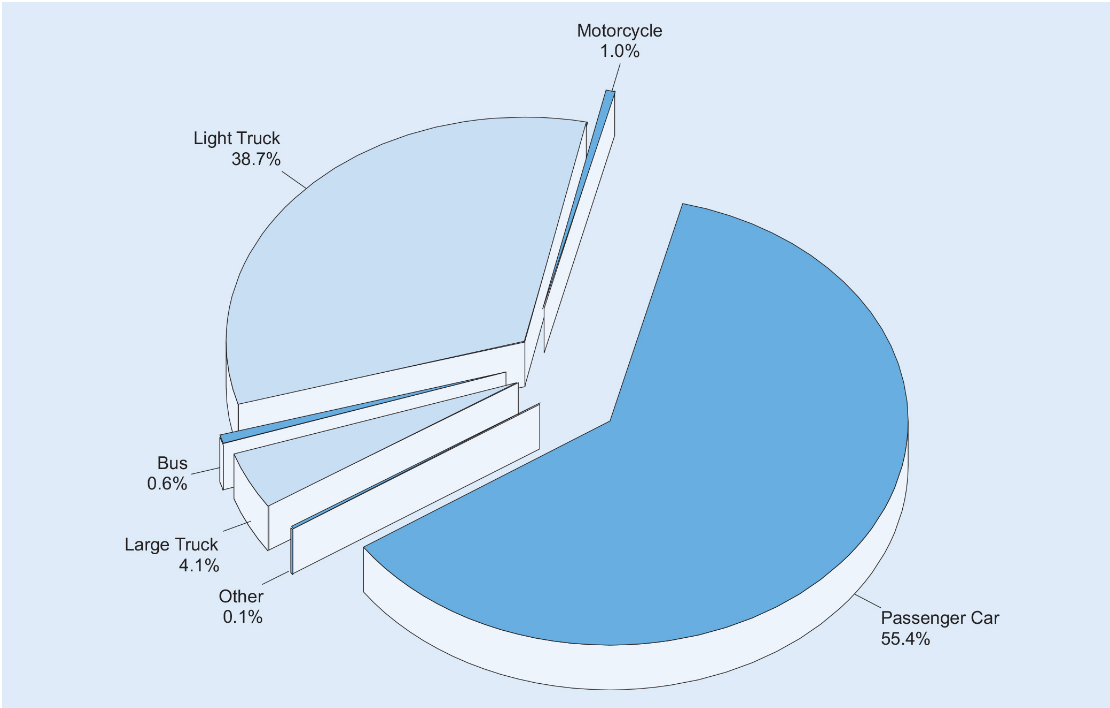

Figure 12-16. Proportion of vehicles involved in traffic crashes (NHTSA, 2014).

Heavy-Truck Safety Data

Drivers of heavy trucks must maintain safe control of their vehicle and be vigilantly aware of other road users. Crashes and critical incidents involving trucks have been investigated to determine causal factors of crashes. Information from interviews with subject matter experts like collision investigators, FMCSA state representatives, and veteran truck drivers implicate other road users as being responsible for performing many unsafe driving acts in the vicinity of large trucks—e.g., driving in the “no zones” (i.e., unsafe zones) like the left rear quarter, right front quarter, directly behind; changing lanes abruptly; driving inattentively; following too closely; changing lanes in front of a truck, then braking, etc. (Stuster, 1999). This could have implications for hazard zones and sensors for collision warning systems. Furthermore, the drivers of passenger vehicles have been shown to be significantly more inclined to engage in reckless driving maneuvers compared to heavy-vehicle drivers (Rosenbloom, Eldror, & Shahar, 2009), which may be associated with the statistical bias towards passenger vehicles being culpable in multi-vehicle safety critical situations that involve both passenger and heavy vehicles (discussed below). The safety data on crashes and near crashes are closely aligned with the opinions of subject matter experts.

Heavy-Truck Crashes – Fatal and Injurious

As shown in Table 12-11, there were a total of 438,000 crashes that involved heavy trucks during 2014.

Table 12-11. Counts for fatal, injury and property damage crashes involving large trucks by impact location (NHTSA, 2014)*

Impact point	Fatal		Injury		Property Damage		Total	
Front	2,152	(57.5%)	43,000	(48.7%)	121,000	(34.9%)	**166,000**	**(37.9%)**
Left Side	372	(9.9%)	10,000	(11.6%)	49,000	(14.1%)	**59,000**	**(13.5%)**
Right side	237	(6.3%)	9,000	(10.4%)	64,000	(18.4%)	**73,000**	**(16.7%)**
Rear	677	(18.1%)	20,000	(22.3%)	85,000	(24.7%)	**106,000**	**(24.2%)**
Non Collision**	159	(4.2%)	5,000	(5.2%)	11,000	(3.1%)	**15,000**	**(3.5%)**
Other/Unknown	147	(3.9%)	2,000	(1.8%)	17,000	(4.9%)	**19,000**	**(4.3%)**
Total	**3,744**	**(100%)**	**88,000**	**(100%)**	**346,000**	**(100%)**	**438,000**	**(100%)**

* Percentages are computed based on the value in the Total row (e.g., there were 2,152 front impact fatal crashes, which is 57.5% of the total 3,744 fatal crashes).

**A non-collision is a class of crash in which the first harmful event does not involve a collision with a fixed object, nonfixed object, or a motor vehicle. This includes overturn, fire/explosion, falls from a vehicle, and injuries in a vehicle (NHTSA, 2014.)

Of note, crash involvement by large trucks increased considerably between 2012 and 2014 (see also NHTSA, 2012) in terms of both the number of crashes (276,000 in 2012 vs. 438,000 in 2014) and the proportion of crashes involving large trucks (2.9% in 2012 vs. 4.1% in 2014).

The Motor Carrier Safety Improvement Act (MCSIA) of 1999 mandated multiple studies to determine the causes of and factors contributing to crashes that involve commercial motor vehicles. The Large Truck Crash Causation Study (LTCCS) was a MCSIA effort that resulted in the most detailed and representative account of truck crashes to date. The LTCCS was a data collection project that occurred over a 33-month period between April 2001 and December 2003 at 24 sites across the United States. The LTCSS data was made available to the public at the close of 2006 and is hosted online at http://ai.fmcsa.dot.gov/ltccs/default.asp (FMCSA, 2006). Another MCSIA study, the Bus Crash Causation Study, is discussed later in this tutorial.

As shown in Table 12-12, the LTCCS contains data from 967 heavy-truck crashes that involved at least one fatality or at least one injury that was either incapacitating or non-incapacitating. The majority of these crashes included more than one vehicle (i.e., there were 726 multivehicle crashes). Trained inspectors obtained almost 1,000 vehicle and driver data elements from each crash. The data elements include the pre-crash conditions of the truck (e.g., brake alignments, lighting and markings, etc.), as well as the conditions of all drivers involved (e.g., experienced, license type, prescription drug-use, etc.), roadway factors, weather conditions, etc.

Table 12-12. Overview of the data sample for the Large Truck Crash Causation Study (LTCCS) (FMCSA, 2006).

LTCCS Sample Statistics	
Total crashes	**967**
Crash Severity Level	
Fatal	223
Incapacitating injury	278
Non-Incapacitating injury	466
Number of vehicles per crash	
Single vehicle	241
Two –vehicles	492
Three or more vehicles	234

Table 12-13 below presents nationally representative estimations of heavy-truck crash types based on the LTCCS data. The national estimates include sampling weights that were applied to the original dataset (e.g., post stratification sampling weights). The sampling weights were based on the probability of a single crash case from the original data sample being selected from a more nationally representative sample of crashes available through the National Automotive Sampling System General Estimates System (NASS-GES).[5] A cursory glance at the first three most prevalent crash types shown in Table 12-13 supports the deployment of FCW, LDW, and SCW systems for heavy trucks, as these three systems seem directly-related to over 50 percent of the estimated crashes. A more thorough examination of the data (Blower, Green, & Matteson, 2010) shows that these systems may need to account for the uniqueness of the heavy-vehicle driving environment, which is an environment where crash culpability for single and multi-vehicle crashes may not necessarily belong to the driver of the heavy vehicle.

The conclusion of FMCSA's (2006) report to Congress indicated that in 55 percent of the total crashes (single- and multivehicle crashes combined) the *critical reason* for crashes was assigned to a truck. There are both driver and mechanical factors associated with multi-vehicle crashes that were assigned a *critical reason* in crashes, which was defined as the immediate reason that caused the precipitating event that lead to the crash (e.g., driver decisions, vehicle failures, highway design features, etc.). A later study by Blower et al. (2010) that used the unweighted LTCCS data showed that of the 1,123 trucks that were included in the LTCCS, 30 percent had one or more mechanical violations (e.g., incorrect brake adjustments, issues with the lighting system, etc.) that would have placed the truck out of service had the violation been discovered before the crash. Likewise, 12 percent of drivers had violations[6] that would have placed them out of service (e.g., moving violations, driver log violations, hours of service violations, etc.). Trucks with mechanical brake violations were 1.8 times more likely to be assigned the critical reason in a multivehicle crash, and in these crashes, the truck was most often the striking vehicle. Drivers with hours of

[5] NASS-GES conducts annual random samples of police reports (PAR) from 400 different jurisdictions in 60 different geographic locations across the United States. Each PAR contains information about a motor vehicle crash that occurred on a traffic way that resulted in property damage, injury or death. Approximately 90 data elements from 50,000 PARs are usually obtained. The sample of crashes is much larger compared to LTCCS but there are almost 10 times fewer data elements per crash.

[6] Violations were recorded as per North American Standard (NAS) Level 1 vehicle inspection protocol, which is included in Federal Motor Carrier Safety Regulations (FMCSR). Inspection forms included options to select 7 carrier violations, 47 Driver violations, and vehicle 127 mechanical violations.

service violations (e.g., driving more than 11 hours after only 10 consecutive hours off-duty, driving more than 60 hours in 7 consecutive days, etc.) and log violations (e.g., submitting false reports, failure to keep an up to date record of duty, etc.) increased the odds of the critical reason getting assigned to the truck by 2 and 2.2 times respectively. These results imply that mechanical and driver violations are associated with crashes in some way. As the LTCCS was not an experiment we can only say that these factors are correlated with crashes and not that they were a causal or contributing factors, only that there is a strong tendency for them to co-occur. In addition, a rather important association in the LTCCS data was that the critical reason was assigned to passenger vehicle drivers in 56 percent of the multi-vehicle crashes that involved both a truck and a passenger vehicle (FMCSA, 2006).

Table 12-13. Estimates of heavy truck crash types (adapted from FMCSA, 2006).

Crash Type	Weighted Crash Count*	Percent**
Rear End***	33,000	23.1%
Ran off Road/Out of Lane	25,000	17.8%
Side Swipe, Same Direction	15,000	10.3%
Rollover	13,000	8.9%
Turning across Path/into Path	11,000	8.0%
Intersecting Vehicles, Straight Paths	8,000	5.8%
Side Swipe, Opposite Direction	6,000	4.6%
Head-on	4,000	3.0%
Hit Object in Road	3,000	1.8%
No Impact (fire, jackknife, other)	1,000	0.9%
Backing into Other Vehicle	<500	0.3%
Other Crash Type	22,000	15.5%
Total Trucks	141,000	100.0%

* The national estimate of fatal, incapacitating and non-incapacitating crashes that involved large trucks that occurred during the LTCCS duration was 141,000. Counts rounded to the nearest thousand.

** Percentage computed after sampling weight were applied to the LTCCS data. Sampling weights were based on the national estimates of large truck fatal and injurious crashes.

*** Rear end crash type includes trucks colliding with the rear end of a non-truck, non-trucks colliding with the rear end of a truck and trucks colliding with the rear end of another truck.

Heavy-Truck Critical Incidents

Observational data also support the notion that it is not necessarily truck drivers who are the problem. There is a complex interplay between heavy and light vehicles that makes it difficult to discern where safety problems exist. Naturalistic data suggest it is more often the light-vehicle driver who initiates a *critical incident* that involves a heavy truck (Hanowski, Hickman, Wierwille, & Keisler, 2007). Critical incidents are explicit situations that do not result in a crash but require the driver to act out a crash avoidance maneuver (e.g., hard-braking or evasive steering). General terms like *close call* and *near miss* are considered synonymous with critical incidents. Critical incidents occur at a much greater frequency compared to actual crashes, which makes their use far easier to draw inferences about safe driving.

Hanowski et al. (2007) analyzed 210 critical incidents that involved combinations of heavy and light vehicles. They found that only 22 percent of the total critical incidents were initiated by the drivers of heavy-trucks, but 78 percent were initiated by drivers of light vehicles. Critical incidents that were initiated by light vehicles were often due to light vehicles *cutting off* trucks while merging into the same lane as the trucks. Critical incidents initiated by light vehicles often occurred at intersections, this is when light vehicles turned left in front of a truck as it approached the intersection from the opposite direction. Drivers of light vehicles often turned when trucks were too close and clearance was not adequate.

When looking at the smaller proportion of critical incidents that were initiated by heavy trucks, there was a stark difference that depended on the type of truck that was involved. Trucks that had local/short haul (L/SH) routes were associated with a greater variety of contributing maneuvers. The primary maneuvers associated with critical incidents were driving straight (i.e., a *through traffic* maneuver) that was associated with 44 percent of the L/SH-initiated critical incidents, and making *right turns* (24%) or *left turns* (12%). Sleeper berth (SB) trucks with long haul routes tended to be associated with one type of maneuver (e.g., the primary maneuver was *through traffic* for 71 percent of the SB truck initiated critical incidents).

Bus Crash Data

In 2007 there were 304 bus crashes that resulted in at least one fatality (Jarossi, Matteson, & Woodrooffe, 2010). This fatality rate appears to be moderately stable through recent history. Over the 5-year period 2003to 2007 there were an average of 318 fatal bus crashes per year (max of 336 and min of 304). People other than bus drivers and passengers on the bus are often the victims of fatal crashes; 62.8 percent of the fatalities were occupants of other vehicles and 26.3 percent were non-motorists (e.g., pedestrians and pedalcyclists)—see Table 12-14.

The majority (87.2%) of fatal bus crashes occurred under normal weather conditions with no rain, snow, fog or other adverse condition and more than half occurred during daylight hours (63.5%). A smaller percentage (7.9%) of fatal bus crashes occurred under rainy conditions.

Table 12-14. Bus crashes during 2007 that involved a fatality by first harmful event (from Jarossi et al., 2010).

First harmful event	School		Transit		Intercity		Charter		Other		Unknown		Total	
Noncollision event														
Overturn/rollover	0	(0.0%)	0	(0.0%)	1	(10.0%)	2	(5.0%)	0	(0.0%)	1	(33.3%)	**4**	**(1.3%)**
Fell/jumped from vehicle	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Other noncollision	1	(0.9%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Collision with motor vehicle														
Motor vehicle in-transport	84	(75.7%)	58	(55.8%)	6	(60.0%)	19	(47.5%)	24	(66.7%)	0	(0.0%)	**191**	**(62.8%)**
Motor vehicle in-transport on different roadway	1	(0.9%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	0	(0.0%)	0	(0.0%)	**2**	**(0.7%)**
Parked motor vehicle (not in-transport)	0	(0.0%)	1	(1.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Collision with nonfixed object														
Pedestrian	15	(13.5%)	33	(31.7%)	2	(20.0%)	5	(12.5%)	3	(8.3%)	2	(66.7%)	**60**	**(19.7%)**
Pedalcycle	6	(5.4%)	9	(8.7%)	1	(10.0%)	1	(2.5%)	3	(8.3%)	0	(0.0%)	**20**	**(6.6%)**
Live animal	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(2.8%)	0	(0.0%)	**1**	**(0.3%)**
Non-motorist on personal conveyance	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Other object not fixed	1	(0.9%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	0	(0.0%)	0	(0.0%)	**2**	**(0.7%)**
Collision with fixed object														
Guardrail face	1	(0.9%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Concrete traffic barrier	0	(0.0%)	1	(1.0%)	0	(0.0%)	4	(10.0%)	3	(8.3%)	0	(0.0%)	**8**	**(2.6%)**
Other barrier	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Highway/traffic sign post/sign	1	(0.9%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	0	(0.0%)	0	(0.0%)	**2**	**(0.7%)**
Culvert	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	1	(2.8%)	0	(0.0%)	**2**	**(0.7%)**
Curb	0	(0.0%)	1	(1.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Embankment - Earth	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Wall	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(2.5%)	0	(0.0%)	0	(0.0%)	**1**	**(0.3%)**
Standing tree	1	(0.9%)	1	(1.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	**2**	**(0.7%)**
Other fixed object	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	1	(2.8%)	0	(0.0%)	**1**	**(0.3%)**
Total	**111**	**(100%)**	**104**	**(100%)**	**10**	**(100%)**	**40**	**(100%)**	**36**	**(100%)**	**3**	**(100%)**	**304**	**(100%)**

NHTSA Traffic Safety Facts 2014 (NHTSA, 2016) provide a general characterization of the relationship of the initial point of impact to crash severity for commercial buses (which includes transit buses, intercity buses, and school buses). Table 12-15 below summarizes these data.

Table 12-15. Counts for fatal, injury and property damage crashes involving buses by impact location (NHTSA, 2016)*

Impact point	Fatal		Injury		Property Damage		Total	
Front	146	(62.4%)	4,000	(39.6%)	15,000	(26.3%)	**20,000**	**(28.6%)**
Left Side	14	(6.0%)	2,000	(16.6%)	12,000	(20.2%)	**14,000**	**(19.5%)**
Right side	24	(10.3%)	1,000	(10.6%)	12,000	(20.6%)	**13,000**	**(19.0%)**
Rear	31	(13.2%)	4,000	(32.8%)	19,000	(32.5%)	**23,000**	**(32.4%)**
Non Collision	4	(1.7%)	<500	(0.3%)	<500	(0.4%)	**<500**	**(0.4%)**
Other/Unknown	15	(6.4%)	<500	(0.1%)	<500	<(0.05%)	**<500**	**<(0.05%)**
Total	**234**	**(100%)**	**11,000**	**(100%)**	**58,000**	**(100%)**	**69,000**	**(100%)**

* Percentages are computed based on the value in the Total row (e.g. there were 146 front impact fatal crashes, this computes to 62.4% of the total 234 fatal crashes).

The Bus Crash Causation Study (BCCS) data, which was the additional study through the MCSIA), was smaller in scope and thus less generalizable than the LTCCS, yet there are some high-level implications that can be drawn from the study. The data collection period for the BCCS occurred from January 2005 to December 2006, and was entirely conducted in New Jersey. There were 40 buses involved in 39 crashes that resulted in at least one fatality or one injury that are included in the BCCS data. Although the small sample size severely limits the generalizability of the BCSS data, it is still the most comprehensive examination of bus crashes available.

An interesting limiting factor was that there was an absence of certain FMCSA safety regulations for transit and school buses that limited the amount of data that could be obtained from these vehicles, but this restriction was not applied toward charter/coach buses. As indicated in the BCCS Report to Congress, only crashes that resulted in a fatality were included for school and transit bus crashes but both fatal and injurious crashes were included for other types of buses. The absence of equivalent safety regulations for buses may be the reason for there being only 400 data elements for each crash in the BCCS, as opposed to the 1,000 elements for the LTCCS. The BCCS data were made available to the public in 2009 and can be accessed from this site: www.fmcsa.dot.gov/facts-research/Bus-Crash-Causation-Study-Database-and-Codebook.aspx (FMCSA, 2009).

The results of an analysis of the BCCS data show that buses were assigned the critical reason for almost half (19 of 39) of the recorded crashes. Table 12-16 shows factors that were coded multiple times for all bus drivers in the study sample. Some factors were also coded as the critical reason for the crash (e.g., inadequate surveillance was coded for 10 drivers as the critical reason for 6 crashes). The top 5 driver factors (e.g. line of sight obstructed, in a hurry, inadequate evasive action, unfamiliar with the road, and inadequate surveillance) loosely correspond with what is currently known about bus driver tasks and workload (see Tse, Flin, & Mearns, 2006; Göbel et al., 1998; and Wei, Becic, Edwards, Graving, & Manser, 2013).

Table 12-16. Bus Driver Factors Associated to Crashes in the BCCS (from FMCSA, 2009).

Associated Factors	Count*
Line of sight obstructed by vehicle, object, sign	22
In a hurry	16
Inadequate evasive action taken	15
Uncomfortable/unfamiliar with the road	11
Inadequate surveillance	10
Made an illegal maneuver	9
Prescription drug use	8
Driver had vision problems	6
Inattention/distraction	5
Impending problem masked by traffic flow	7
Distracted by a person, object, or event	7
Line of sight obscured by weather, poor light	7
Misjudged gap or velocity	7
Following too close	3
Driver had hearing problems	2
Traveling too fast	2

* Many of the Associated Bus Driver Factors were counted more than once across the sample of bus crashes.

Driver Tasks and Workload for Drivers of Heavy Trucks and Buses

This section of the tutorial discusses the tasks and associated workload that are experienced by drivers of large vehicles like heavy trucks and buses.

Heavy-Truck Driver Tasks and Workload

NHTSA supported a 4-year program during 1991 to 1995 to provide insights about the heavy truck driving environment that could be used for introducing advanced technologies into the heavy truck cab. Other than from the efforts of this NHTSA program, tasks and workload for drivers of heavy trucks has largely been ignored. Most of the available literature about truck driving in the United States approaches topics like driver fatigue and crash risk but does not focus on what drivers of heavy trucks are actually doing while they drive. On the other hand, European researchers have recently started cataloging tasks done by drivers of heavy trucks (e.g., Wohlfahrt & Niegemann, 2011) but for the purposes of understanding workload and driver tasks, even these tasks are provided at too high a level to use as input on design of DVIs. Example tasks these authors list are: (1) observing traffic rules, (2) driving in a way that the load is transported safely, (3) maneuvering, (4) steering, and (5) adapting driving to weather and traffic conditions. Currently, there is a need for more granular, detailed information about driving tasks and the needs of heavy-truck drivers.

Initial findings from the NHTSA program (Turanski & Tijerina, 1992) provide a list of heavy truck driving tasks categorized under six conceptual categories. These categories and tasks are presented in Table 12-17. This early work is detailed but is also missing information about specific job and driving related tasks that occur while driving a heavy truck for commercial purposes. There is far more detail about the driving tasks for transit bus operators, as discussed in the next section.

Table 12-17. Driving tasks for heavy-truck drivers (from Turanski & Tijerina, 1992).

Basic Driving Tasks	• Start vehicle in motion • Shift gears • Reach desired speed in each gear • Reach desired cruise speed • Control truck speed to allow for safe stopping distance* • Brake under normal circumstances* • Maintain safe following distance* • Control direction via the steering wheel* • Maintain lane position and spacing, straight road* • Be aware of changes in road scene (primary visual task)* • Glance at gauges • Glance at mirrors* • Drive on a downgrade (steep gradient) • Drive on an upgrade
Lane Changes and Passing/Overtaking	• Change lanes* • Pass on the left, cars (multi-lane, divided road) • Pass on the left, other trucks (multi-lane, divided road) • Pass on the left, cars (two-lane, undivided road) • Pass on the left, other trucks (two-lane, undivided road) • Pass construction zones • Merge* • Exit using an exit ramp
Turns and Curves	• Make a left turn • Make a right turn • Negotiate a curve and remain in your lane* • Negotiate a curve and change lane in a multi-lane divided highway* • Turn your tractor-trailer around
Intersections and Crossings	• Travel through intersections (You have right-of-way) • Stop at intersections (They have right-of-way) • Start truck in motion from a stop at an intersection • Cross railway grade crossings • Negotiate l-lane and narrow 2-lane bridges* • Negotiate narrow lane tunnels* • Stop at and start from narrow-lane toll plaza
Parking and Related Activities	• Park tractor-trailer • Back-up
Nonstandard Driving	• Recover from locked brakes due to extreme loss of air pressure • Make a quick stop (Put a lot of pressure on brakes, but with no smoking tires, no danger of losing control) • Make a hard braking stop (smoking tires, danger of losing control) • Stop due to lighting problem (e.g., trailer lights go out) • Stop due to engine problem (e.g., high engine coolant temperature, low oil pressure) • Recover from tire failure, front tires • Recover from tire failure, other tires • Steer to avoid something on the road • Recover from a tractor/trailer skid • Respond to cargo or tire fire • Execute off-road recovery (veer off the road to avoid collision, then immediately return to roadway)

* Tasks with an asterisk were identified by Turanski & Tijerina (1992) as those most relevant to in-cab device interaction.

Other projects that occurred during the NHTSA program found that heavy-truck drivers adapted well to changes in workload associated with the road types, ambient lighting (e.g., night and daytime), and traffic (e.g., car following). For example, heavy-truck drivers allocated 90 percent of their visual resources to looking at the roadway while driving at nighttime on 2-lane highways, but only 70 to 75 percent for daytime 4-lane rural expressways (Tijerina et al., 1995).

The workload demands of driving a heavy-truck are typically viewed as greater than those for passenger vehicles; this is due to more complex vehicle control operations (e.g., steering, shifting, and braking). Heavy-truck driver opinions appear to be consistent with this general view. Kiger et al. (1992) conducted a task analysis and initial assessment of heavy truck driver workload as part of their larger effort to develop measures of driver workload. As part of a larger survey, drivers were asked to rank eight common tasks from "1" to "8" in order of increasing workload; where a "1" means the task causes the lowest workload, while an "8" means the task causes the highest workload. Table 12-18 presents the mean rank orders. The results are insightful but should be interpreted with caution as their sample size (n = 21) was inadequate to draw significant conclusions. Again, we see that drivers are sensitive to the workload demands of driving and that common driving tasks vary substantially in the amount of workload perceived to be involved.

Table 12-18. Mean rated workload of common driving tasks (adapted from Kiger et al., 1992).

Task	Mean	Std. Dev.
Check your mirrors	2.33	1.35
Eat or smoke while driving	2.42	1.94
Change lanes	3.57	1.53
Pass another vehicle on the left	4.24	1.48
Enter a freeway	4.48	2.20
Negotiate a curve and stay in your lane	5.14	1.68
Make a turn at an intersection	6.62	1.24
Driving through a construction zone	7.19	1.25

Kiger et al. (1992) also conducted a series of interviews to gain a more complete understanding of how heavy-truck operators defined workload and its contributing factors. They found that both the operational and driving environments both contribute to stress and workload and therefore concluded that it is essential to control these factors in any studies attempting to assess driver workload. In addition, Tijerina and his colleagues noted that an evaluation of driver systems would best be conducted under demanding conditions, including inclement weather, congested traffic, and roadway construction zones (Tijerina et al., 1995).

Bus Driver Tasks and Workload

Research on occupational aspects of bus driving has been conducted since the early 1950s (for a review see Tse et al., 2006) and there are numerous occupational stressors that bus drivers experience, many of which occur when transporting passengers. Bus driver tasks include managing the boarding and alighting of passengers (e.g., taking in cash fares, handing out transfer tickets, etc.); providing passengers with route information, driving through busy intersections, picking up passengers, and coordinating travel speed to match the route schedule. All of these driving-related tasks are often performed with restricted lines of sight in congested traffic conditions and quickly under the tight time constraints of their bus-stop schedule.

During initial stages of a project conducted to redesign the work areas of transit buses manufactured and operated in Germany, Göbel et al. (1998) conducted task analyses and assessed the stress and workload of transit bus operator duties. These researchers observed eight transit bus operators complete a transit driving sequence on one of four bus types in one of four German cities. They also collected and analyzed driver gaze data using a head-mounted eye-tracking device that had an approximate accuracy of 1° field of view. Gross measures of transit bus gaze direction indicated that the majority of gaze time was directed outside of the bus, followed by mirror observation, gazes near the window jambs, customer service objects, and instruments, as summarized in Table 12-19.

Table 12-19. Distribution of transit bus driver gaze times (Göbel et al., 1998).

Gaze Direction	Percentage of Total Time
Outside Bus	73.2
Mirrors	10.2
Window Jambs	8.4
Customer Service Objects	5.0
Instruments	3.2

Göbel et al. (1998). Stress and strain of short haul bus drivers: Psychophysiology as a design oriented method for analysis. *Ergonomics, 41*(5), Taylor & Francis Ltd. [4]. Reprinted by permission of the publisher.

Göbel et al. (1998) obtained gaze frequency and duration measures at a relatively fine level of activity resolution (see Table 12-20). The results in the table illustrate a scanning strategy of short gazes at any one location. Gaze directions toward the forward, left and right views outside the bus are quite short at around three-quarters of a second. If these gaze times are valid, they represent a pattern that is quite distinct from the gaze times of heavy-truck drivers (Tijerina et al. 1995), where average forward roadway gaze durations were between 2.4 and 5.2 seconds, depending on the type of roadway. When Table 12-19 and Table 12-20 are considered together, one can see (at least according to this research) that bus drivers spend a large portion of their total drive time gazing outside the bus at different locations and that each gaze is of a very short duration. To the casual reader this may imply that bus drivers are constantly scanning and changing where they are looking, and the additional literature on driver training and driver tasks supports this notion. In this regard, of particular concern to DVI design is not the average glance durations of the type seen in Table 12-20, but instead the frequency of especially long glances (see also Horrey & Wickens, 2007)

Although additional research is required to determine how these results impact DVI design, a plausible assumption is that measured glance durations, like Göbel et al. (1998) may be appropriate for benchmark estimates of timing requirements for the design of visual information. In this sense, if we assume that measured drivers' scan patterns and gaze durations are normative, then the amount of time it takes a driver extract the information from DVI should correspond to typical gaze durations toward the region where the DVI is mounted. Of course, it is well known that the way drivers prioritize elements in their driving environment and the driving complexity of different tasks influence where and for how long drivers look at various locations. Göbel et al. (1998) found that a visually simplified and ergonomically appropriate instrument panel reduced operational task duration by 23 percent, which they attributed to a simplified visual scan path that resulted from the modified design. Their newer design consisted of reducing the number of visual elements on the dashboard, and ensuring clear and comprehensive information presentation.

Table 12-20 Distribution of transit bus driver gaze frequencies and durations (estimated from Göbel et al., 1998).

Gaze Direction	Estimated Rate (per hour)	Estimated Mean Duration (sec)
Outside Left	123	0.70
Outside Front	635	0.70
Outside Right	78	0.70
Left Mirror	185	0.60
Inside Mirror	98	1.05
Right Mirror	152	0.65
Left Jamb	230	0.70
Right Jamb	102	0.70
Speedometer	45	0.65
Control Switch	38	0.70
Control Lamp	29	0.55
Specific Instrument	26	0.73
Passenger Door	25	0.76
Customer	25	0.85
Cash Box	72	1.30
Money	23	1.65

Göbel et al. (1998) note that service tasks performed when buses arrive and depart from stops increase stress and strain on bus drivers. Driver stress increases sharply when responding to invalid tickets, and driving in the rain. These factors have equal negative effects on heart rate variability—a validated predictor of stress. Mirror usage, opening doors and wait-time also affect heart rate variability in a negative way, but only moderately so compared to invalid tickets and driving in the rain. These activities and their impact on workload should be considered during development of transit DVIs.

Another interesting finding from Göbel et al. (1998) was related the design of the buses. In Germany at the time of the study, bus drivers had to act out ergonomically uncomfortable movements in order to collect fares and check tickets, and glances toward mirrors also tended to be a problem due to poor design. As reported by Göbel et al. (1998), changes in bus instrument panel design facilitated many driver tasks that were not necessarily associated with information picked-up from the instrument panel (e.g., checking mirrors and ticketing).

Bus drivers carry out driving tasks such as maintaining lane position, adjusting speed, turning the vehicle, looking at mirrors, etc. But there are also service operation tasks that bus drivers carry out like taking tickets, handing out transfers, and managing their schedule. In an effort to better understand the tasks bus drivers carry-out during a specific situation―while making left turns at intersections―Wei et al. (2013) conducted focus groups with bus drivers to learn more about such tasks. During their focus groups they worked with bus drivers to describe driving tasks and where these tasks occur when turning left at a signalized intersection. Their findings are limited to intersections that do not have a protected left-turn signal, which was an intentional part of their research because intersections without protected left-turn signaling are associated with a large amount of collisions between buses and pedestrians. The tasks that were included in their analyses were organized into categories that represented the different phases of approaching an intersection to make a left turn (see Figure 12-17). The key conclusion from the table relates simply to the absolute volume of tasks and the types of tasks that can occur while drivers are carrying out a left turn, which is a rather complicated maneuver in itself. Many of the listed tasks can occur at a variety of different times throughout the left turn maneuver (e.g., monitoring the signal status) but the priority of each task is dynamic and can become higher or lower in priority depending on the interplay between the bus and what is going on in the environment. For example, if the driver is approaching an intersection with a “fresh green” they may prioritize the tasks associated with their approach to the next bus pickup over the driving tasks associated with making the left turn. Wei et al. (2013) indicate that drivers in their study mentioned that experience would mitigate such a mis-prioritization of operational tasks over safe driving tasks, but the authors indicate that further research is required to make any substantial conclusion.

Interestingly, Göbel et al. (1998) also found that bus drivers perform multiple tasks 80 percent of the time they are driving, although the tasks they reported are a bit less complicated (e.g., accelerating and activating turn signals, slowing down and opening doors, conversing with passengers and opening doors).

Approach
1. Plan bus departure
   a. Determine how many lanes to be crossed
   b. Change lanes (4 lanes/ 3 lanes/ 2 lanes)
2. Assess tail-swing to ensure tail clearance from curb and maintain lane position
3. Scan surroundings for unsafe situations or obstacles
4. Look up at the intersection
5. Observe the traffic signal
6. Modulate approach velocity; at this position, if the light is red the driver may speed up in order reach the intersection when the signal changes to green
7. Check for relevant road features

Approach / Deceleration
1. Complete lane changing (if more than 2 lanes)
2. Maintain lane position
3. Check surroundings; scan for unsafe situations or obstacles and monitor position of bikers
4. Look up at the intersection; observe distance to intersection and modulate speed
5. Observe the traffic light to judge maneuver completion time based off of signal status:
   - If the driver saw the signal change from red to green (i.e., a fresh green) driver will estimate left-turn and modulate approach speed as needed.
   - If the driver did not see the signal change (i.e., stale green) driver will not estimate maneuver completion time and will anticipate stopping at the intersection. Brakes are always applied early ("easy on brakes", "smooth stop")
6. Determine location of next bus stop

Deceleration / Acceleration
1. Maintain lane position
2. Scan surroundings for unsafe situations or obstacles
3. Observe road features; if there is a median, bus is driven close to curb to prevent biker access
4. Look up at the intersection and observe distance to intersection
5. Observe traffic light
6. If stop is required: plan to stop 1 car length behind crosswalk or leave 1 car length between bus and lead vehicle at intersection to "leave an out"

Intersection Entry
1. Observe surroundings
   a. Determine the types of vehicles that will turn with the bus at the intersection
   b. Monitor oncoming traffic
   c. Observe for pedestrians
   d. Check mirrors
2. Wait for any leading traffic to turn left
   a. Allow for a 4-second pause before proceeding
   b. straighten bus to ensure no encroachment on adjacent lane
3. Scan to the right (for red light violators)
4. Scan to the left
5. Assess on-coming traffic for gaps
6. Scan for pedestrians and bicyclists
7. Glance down the sidewalk to the left of the driver
8. Turn the wheel
9. Check for curb on right of bus – avoid a curb strike

Prepare to Turn / Execute Turn
1. Observe road features
2. Glance again down sidewalk
3. Quick glances forward, left sidewalk, then right mirror
4. Maintain wheel position as straight to prevent collision with oncoming traffic from accidental acceleration of the bus
5. Determine entrance lane ("money lane", "right lane")
6. Determine angle of turn
7. Select gap in oncoming traffic or wait until signal turns red if traffic does not permit left turn

Post Turn
1. Reduce speed
2. Signal and move to the right lane
3. Locate bus stop position
4. Observe road features; if in left lane, determine how much time/space for merging right to prepare for bus stop
5. Check for pedestrians running for bus at the last minute

Figure 12-17. Transit bus driver task analysis for Minneapolis Metro Transit (Wei et al., 2013).

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Chapter 13. Glossary

Active Haptic Interfaces
: Signals delivered through control devices to enhance responses such as haptic steering wheel displays that activate when steering responses are most appropriate or haptic accelerator pedal displays that activate when changes to acceleration or speed are desired.

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
: 1/60 of one degree.

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

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.

Azimuth
: Horizontal aspect of an angular measurement in a spherical coordinate system. In terms of spatialized audio, humans can more easily perceive the location of a sound in the horizontal plane (i.e., left to right or azimuth) than in the vertical plane (i.e., up and down or elevation).

Cognitive Distraction
: "Any physical manipulation that competes with activities necessary for safe driving" (Foley, Young, Angell, & Domeyer, 2013).

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.

Connected Vehicle Technology
: Communication systems designed to send short-range safety and mobility messages between vehicles and the roadway infrastructure to improve the safety of drivers, passengers, and pedestrians; prevent injuries; and ease traffic congestion.

Continuous Control
: A control mechanism that provides a continuous range of value options.

Control Coding
: The set of design characteristics that serve to identify the control or to identify the relationship between the control and the function to be controlled.

Correspondence Problem
: In regard to vibrational signals, the meaning of the signal must be learned by the driver as it is not a naturally correspondent cue.

Difference Threshold
: The minimum change between signals or within a signal that results in there being a detectable change, or detectable difference.

Discrete Control
: A control mechanism that provides distinctive, individual values options.

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

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 (Auto Alliance, 2006).

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

Dwell Time
The total duration of all glances, fixations and other eye movements within a defined area that contains the visual target.

Dynamic Integrator
A component of an information delivery system that will prioritize and control delivery of a variety of in-vehicle messages to prevent information overload or inappropriate distraction from driving tasks.

Earcon
Abstract musical tones that can be used in structured combinations to create auditory messages that are also referred to as complex tones.

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

Fixation
Fixation occurs when the eyes are aligned with the target and the duration is typically recorded.

Flash Rate (Frequency)
In a visual display, the number of signal flashes per second.

Fluting
The groove pattern on a control.

Forward Glance Decision Time
The difference between the start of a glance and desired response.

Free Running Distance
The product of driver brake reaction time and vehicle speed used in a basic equation for the timing of an FCW (ISO 15623).

Fundamental Frequency
The lowest frequency in a periodic signal.

Ganged Control
Control knob design in which two or more controls are stacked and operable either together or separately.

Gaze Variability
The standard deviation in eye positions as measured during a test interval; vertical and horizontal variability can be reported as separate measures (Caird et al., 2008).

Glance Frequency
The number of glances to a target within a pre-defined sample time period, or during a pre-defined task, which are separated by at least one glance to a different target.

Glance Probability
A measure of the proportion of transitions to the specific location of interest that is obtained by dividing the sum of all transitions to a specified location by the sum of all transitions between all pairs of locations occurring during the sample interval.

Glance
The time from the moment at which the direction of gaze moves toward a target (e.g., saccade toward the interior mirror) to the moment it moves away from target—i.e., this includes the transition time to that target and dwell time (SAE J2396).

Glare
: A visual phenomena that 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).

Graded Display
: Visual presentation of the information as successive stages, indicating a trend.

Graded Warning
: A warning that can progress through two or more stages.

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
: 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—that 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
: 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 for Connected Vehicles Program
: U. S. Department of Transportation research program to study and plan for counteracting any unintended distractive consequences the broad spectrum of vehicle-to-vehicle communications may have for drivers.

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.

Icon Display
: A display using a symbol to represent the information.

Information Unit
: The smallest useful piece of information in a message that can stand alone in both meaning and context.

Integration Architecture (Human Factors Connected Vehicles-based)
: A system governing the delivery of information to the driver so that safety-relevant messages are presented in a timely and effective manner.

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.

Knurling
: The protruding, ridging pattern on a control.

Lane Change Decision Aid Systems
: Collision warning systems, such as Blind Spot Warning or Lane Change Warning, that warn the driver of the subject vehicle against potential collisions with vehicles to the side and/or to the rear of the subject vehicle, and moving in the same direction as the subject vehicle during lane change maneuvers.

Lane Exceedance
: Movement of the vehicle into the next lane or shoulder.

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

Link Value Probability

The probability of a glance transition between two different locations obtained by dividing the total number of glance transitions from one location (A) to another (B) plus the number of glance transitions from B to A by the total number of glance transitions between all pairs of locations occurring in the sample interval.

Longitudinal Warning Systems

Collision warning systems, such as Forward Collision Warnings, 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

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/m2).

Manual Distraction

"Any physical manipulation that competes with activities necessary for safe driving" (Foley, Young, Angell, & Domeyer, 2013).

Masked Threshold

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

Master Warnings

A single alert for multiple safety applications.

Mental Model

The user's understanding of a system's underlying operational functions and processes.

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: extraction, recognition, and interpretation.

Message Priority

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

Method of Constant Stimuli

A method to establish a threshold determined by presentation of a series of stimuli repeatedly in a random order for a binary response (e.g., present/absent) from participants. The threshold is determined based a percentage of correct detection (e.g., 75% correct is mentioned in the topic on page 8-12).

Motion Cues

Visual display alerts that contain an element of motion within the "on" state, including bouncing, zooming, and graphical movement.

Motor Priming

A type of response priming where the response is thought to be influenced by a stimulus or signal presented at an earlier time. In research on body motion, motor priming is thought to be a neuronal activity that "pre-activates" that limb motions to use.

Multimodal Warning Message

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

Negative Polarity

A visual display with white text or objects against a black background.

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.

One-stage Warning System
A system in which only a single warning, intended for immediate corrective action, is provided. Also referred to as a single-stage warning.

Operational Relevance
"Degree to which the information [item] increases the ease and convenience of the driving task" (SAE J2395).

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.

Passive Haptic Interfaces
Haptic signals delivered to body areas that are not used to carry out the corrective response such as vibrotactile seat displays for delivering messages about hazard locations, lane departures, intersection violations, or curve speed.

Peripersonal Space
An area within arm's reach.

Point of Regard
The term is used to indicate when the head position needs to be taken into consideration in order to get an accurate measurement of the gaze position; either the head must be stabilized so the eye's position relative to the head and the POR correspond, or other ocular attributes need to be calculated to account for head movement and eye rotation. The attributes that need to be calculated for true gaze tracking with free head movement are corneal reflection and the pupil center.

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 [3] 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 that can be given at the same time using two or more modes or repeated across time with either the same or different modes.

Representational Display
A visual display presenting the information as a realistic graphic rather than as an icon or symbol.

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).

Saccade
The eye-movement that leads up to any fixation on a target or within a target region.

Safety Relevance
"Degree to which [the] information [item] affects the safe operation of the vehicle" (SAE J2395).

Scene Plane
Forward-facing view of the driving scene.

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 that distracts a driver's attention away from the main driving task at hand.

Semantic
Pertaining to the meaning of words or symbols contained in an auditory or visual message.

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.

Serif
: The decorative lines at the end of a letter or symbol's stroke; they can aid the eye in distinguishing letters from each other, but also can add visual clutter.

Signal Word
: A word used to alert the driver to the presence of a hazard, as well as to denote the relative level of severity of the hazard.

Smooth Pursuit Eye Movements
: Eye movements that smoothly track or follow a moving object rather than in discrete steps.

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

Stimulus-Response Compatibility
: A relationship concept such that more compatible mappings between displays and their desired responses require fewer mental operations from display to response than do less compatible displays.

Strokewidth-to-Height Ratio
: A font characteristic that consists of the ratio of the line (stroke) thickness to the height of the character.

Tell-tale
: An indicator that displays the status of a situation or system.

Time-to-Initial-Transition
: The amount of time between the onset of a visual element or alert in the driver's field of view and the last glance from an area of interest such as a display with a distraction task (Perez et al., 2009).

Transport Information and Control Systems
: Systems that 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.

Two-Stage Warning System
: A system in which the immediate corrective action warning is preceded with an informative or immediate attention warning.

Urgency Mapping
: A type of mental model that represents the level of urgency of a situation based on the characteristics of the signals associated with the situation.

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.

Verbal Knowledge
: Information conveyed through words, as opposed to hands-on or demonstrated instruction.

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

Visual Distraction
: "Any glance that competes with activities necessary for safe driving" (Foley, Young, Angell, & Domeyer, 2013).

Width-to-Height Ratio
: A font characteristic that consists of the ratio of the width of a character to the height of the character.

Chapter 14. Index

Chapter 15. Abbreviations

AAM ... Alliance of Automobile Manufacturers
AASHTO ... American Association of State Highway and Transportation Officials
ABS ... anti-lock brake system
ABSZ ... adjacent blind spot zone
ACAS ... Automotive Collision Avoidance System
ACC ... adaptive cruise control
ACWS ... advanced collision warning system
ADA ... advanced driving assist
ADAS ... advanced driver assistance system
AHS ... Automated Highway System
ATIS ... Advanced Traveler Information System
BCCS ... Bus Crash Causation Study
BSMS ... blind spot monitoring system
BSW ... blind spot warning
CAMP ... Crash Avoidance Metrics Partnership
CAS ... collision avoidance system
CCW ... cautionary crash warning
CDL ... Commercial Driver's License
CICAS ... Cooperative Intersection Collision Avoidance System
cm ... centimeter
CSW ... curve speed warning
CV ... connected vehicle
CWS ... crash warning system
dB ... decibel
dBA ... decibel (A-weighted)
DNPW ... do not pass warning
DSRC ... dedicated short range communication
DVI ... driver-vehicle-interface
DWM ... driver workload metrics
EEBL ... emergency electronic brake light
FCW ... forward crash warning
FMCSA ... Federal Motor Carrier Safety Administration
FMVSS ... Federal Motor Vehicle Safety Standards
FOT ... field operational test
FTA ... Federal Transit Administration
g ... acceleration/deceleration level (1 g = approx. 9.8 m/s^2)
GIS ... geographic information system

GVWR.......gross vehicle weight rating
HC.......heading control
HFCV.......Human Factors for Connected Vehicles
HHDD.......high head-down display
HID.......high-intensity discharge
HMI.......human-machine interface
HOS.......hours of service
HUD.......head-up display
HV.......heavy vehicle
HVAC.......heating, ventilation, and air conditioning
Hz.......Hertz
ICW.......imminent crash warning
IMA.......intersection movement assist
IMSM.......interruption management stage model
IP.......instrument panel
ISA.......intelligent speed adaptation
ISO.......International Organization for Standardization
ITS.......Intelligent Transportation Systems/Society
IVBSS.......Integrated Vehicle-based Safety System
IVIS.......In-Vehicle Information System
IVW.......in-vehicle warning
JAMA.......Japan Automobile Manufacturers Association
kHz.......kilohertz
km/h.......kilometers per hour
LCDAS.......lane change decision assist system
LCT.......lane change test
LCW.......lane change warning
LDW.......lane departure warning
LED.......light-emitting diode
LHDD.......low head-down display
LH/S.......local/short haul
LTCCS.......Large-Truck Crash Causation Study
m.......meter
MCSIA.......Motor Carrier Safety Improvement Act
mm.......millimeters
MRT.......multiple resource theory
ms.......millisecond
MT.......masked threshold
NASS-GES.......National Automotive Sampling System General Estimates System

nm .... nanometer
OEM .... original equipment manufacturer
OSHA .... Occupational Safety and Health Administration
POI .... priority order index
PLATO........ Portable Liquid-Crystal Apparatus for Tachistoscopic Occlusion
PTDI .... Professional Truck Driver Institute
PTT........ push-to-talk
RCW .... reverse collision warning
ROR .... run off road
RT........ reaction time
s........ second
SAE .... Society of Automotive Engineers
SB........ sleeper berth
SCW .... side collision warning
SDLP .... standard deviation of lane position
SME........ subject matter expert
SNR........ signal-to-noise ratio
SODS .... side object detection system
SPL........ sound pressure level
TEORT .... total eyes-off-road time
TGT .... total glance time
TICS .... Transport Information and Control Systems
TLC........ time-to-line crossing
TNO........ Netherlands Organization for Applied Scientific Research
TSOT........ total shutter-open time
TTC .... time-to-collision
TTT........ total task time
TWA .... time-weighted average
V2I .... vehicle-to-infrastructure
V2V........ vehicle-to-vehicle
X2D .... vehicle or infrastructure-to-device

Chapter 16. Equations

Page Number

ISO 15623 The Basic Equation of Collision Warning 4-8

$$D = V_1 \text{ x } T + (V_1^2/2a_1 - V_2^2/2a_2)$$

Where:

- D = Distance to the preceding obstacle
- V_1 = Speed of the connected vehicle
- V_2 = Speed of the lead vehicle
- T = Reaction time of the connected vehicle driver
- a_1 = Deceleration of the connected vehicle
- a_2 = Deceleration of the lead vehicle

ISO 15623. (2013). Transport information and control systems - *Forward vehicle collision warning systems - Performance requirements and test procedures*. Geneva: International Organization for Standardization.

Page Number

6-8

Viewing Distance and Symbol Height

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

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

Campbell, J. L., Richard, C. M., Brown, J. L., & McCallum, M. (2007). *Crash warning system interfaces: Human factors insights and lessons learned* (Final report. Report No. DOT HS 810 697). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2007/CWS_HF_Insights_Task_5_Final_Rpt.pdf

6-14

Glare Angle and Display Luminance

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

Where:

L_{veil} = Veiling luminance (cd/m^2)
E_{glare} = Illuminance at the eye from glare source (lux)
θ = Glare angle ($0.1° < \theta < 30°$)
A = Driver age (years)

Adapted from CIE 146:2002. (2002). *CIE equations for disability glare*. Vienna, Austria: International Commission on Illumination. Used with permission.

Page Number

Minimum Density of Vibrating Motors 8-8

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

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

Where:

Aw = Area width
Ah = Area height
T = Two-point threshold

Based on Reiner, A. (2010). *Sensor-actuator supported implicit interaction in driver assistance systems*. Wiesbaden, Germany: Vieweg+Teubner.

Resumability Ratio (R) 12-13

$$\frac{TSOT}{TTT_{Unoccl}}$$

Where

TTT_{Unoccl} = Total Task Time in Un-occluded Conditions
TSOT = Total Shutter-open Time

Based on ISO 16673. (2007). *Road vehicles—Ergonomic aspects of transport information and control systems—Occlusion method to assess visual demand due to the use of in-vehicle systems*. Geneva: International Organization for Standardization.

Chapter 17. 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 that 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).
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.

Document	Description
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 that 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.
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.

Document	Description
ISO 15623 Transport information and control systems--Forward vehicle collision warning systems--Performance requirements and test procedures Year: 2013 Document Type: International Standard	Specification of performance requirements and test procedures for systems that warn the driver of short inter-vehicle distance and closing speed that could cause a rear-end collision with other vehicles. Applicable to operations on roads with curve radii over 125 m.
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 that 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 that provide warnings only (no automatic mitigation action) for passenger cars, commercial vehicles and buses.
ISO 17386 Transport information and control systems-Manoeuvering 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, pick-up 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).

Document	Description
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/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 that discusses efficiency, acceptance of different modalities and combinations of warnings, and design parameters of visual, auditory and tactile warnings.
ISO/TS 14198 Road vehicles--Ergonomic aspects of transport information and control systems--Calibration tasks for methods that 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.

Document	Description
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).
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 that 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 that 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 that 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 that 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 that is then used to determine the order that simultaneous, or overlapping, in-vehicle messages are presented to the driver.

Document	Description
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 & 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).
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 that 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.

Document	Description
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 J2944 Operational Definitions of Driving Performance Measures and Statistics Year: 2015 Document Type: Recommended Practice	Functional definitions and guidance for performance measures and statistics for driver/vehicle responses that affect lateal and lingitudinal positioning of a road vehicle, enabling consistency in calculating and reporting measurements and statistics for comparison across standards, journals, proceedings, technical reports, and presentations.
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.

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