Driver Vehicle Interface Design Assistance for Vehicle-to-Vehicle Technology Applications

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ABSTRACT

This paper provides an overview of the program of research involved in the development of a set of driver-vehicle interface (DVI) design assistance intended for vehicle-to-vehicle (V2V) technology applications. The research reviewed and performed under the NHTSA sponsored program of research (Human Factors for Connected Vehicles (HFCV), Safety Pilot DVI Evaluations, Driver Issues, and Integration Strategy) will culminate in a DVI Design Assistance Document for V2V technology applications. The results of the research will inform this document, which will be a set of Design Assistance topics and will describe appropriate human-centric design attributes for the DVI.

INTRODUCTION

Automotive DVI research in general has typically focused on the design of safety system DVIs. Therefore, the available research used to inform this DVI Design Assistance Document is primarily drawn from safety research. However, the basic design assistance that this document provides may help inform the design of non-safety related DVIs (i.e., infotainment and driver convenience systems) for V2V. Additionally, this document provides information from recent and ongoing research in the emerging field of V2V technology.

Objectives

The overall objective of the HFCV research program is for V2V technologies and applications to have DVIs that effectively communicate safety information while managing driver workload and minimizing distraction. This objective will be realized with the product of this research program, the DVI Design Assistance Document, and will aid in the design of relevant system interfaces to be more effective without increasing distraction or creating high workload.

Goals

The goal of the DVI Design Assistance Document is to aid the design of interfaces that are effective without increasing distraction**.** Warning system interfaces are effective if they (1) attract the driver's attention, (2) communicate the intended information, (3) communicate the information in a way that is immediately understandable so the driver can process the information, and (4) directs attention to a threat in time for the driver to take corrective action. The DVI Design Assistance Document were informed by previous research and current ongoing research performed in the course of the HFCV research program. The research program and design assistance provide information for a better understanding of driver behavior, improved driver assistance technologies, interface design assistance for vehicle-to-vehicle communications technologies aimed at passenger vehicles, heavy trucks, and transit vehicles. The NHTSA's primary concern is safety applications, but the research and design assistance also cover some mobility and sustainability applications for V2V.

In order to realize these goals and objectives, the research program approach included a number of phases and simultaneous tracks that informed the DVI Design Assistance Document. The program began with a definition of the problem, which split into two main tracks of research: one focusing on V2V information and how it should be integrated and managed to better suit the driver's needs, and the other focused on characterisitcs of the DVI and how different safety messages should be delivered to the driver. The HFCV program also engaged stakeholder throughout the DVI Design Assistance development in order to improve the format and content of the DVI Design Assistance Document.

DVI DESIGN ASSISTANCE DOCUMENT

The topics within the V2V DVI Design Assistance Document are informed by the best available scientific research, and the DVI Design Assistance Document is a collection of focus areas uncovered by research that are intended to inform and assist DVI designers in making decisions regarding potential issues with various aspects of the DVI. Each focus area includes an introduction that first defines the topic and how it might be problematic, then the focus area summarizes the functional design goal with supporting design assistance. The focus area then includes a discussion of the practical design issues and the supporting available scientific research.Each focus area of the V2V DVI Design Assistance Document is organized into an easy-to-read, two-page format.

Overall, this document provides goals and assistance for the design and development of V2V DVIs, for both light- and heavy-vehicles, based on knowledge of driver capabilities and limitations. It consists of a series of chapters containing DVI design assistance. Each chapter provides 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 (Chapters 12 through 18), including 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 assistance and tutorials. Figure 1 below provides a high-level overview of the chapters and topics included in the DVI Design Assistance Document.

Chapter 1. Introduction
Chapter 2. How to Use this Document

Chapter 3. General DVI Considerations
- Distraction
- General Workload Considerations
- Workload from Secondary Tasks
- Providing Drivers with Information on System Function and System Messages
- Developing Driver Training Materials

Chapter 4. Principles for Safety Messages
- False and Nuisance Warnings
- Multimodal Warning Messages
- Warning Stages
- Providing Warnings that Accommodate Driver Brake Reaction Time
- Using Coverage Zones to Provide Lane Change Information

Chapter 5. Message Characteristics
- Designing Messages for Driver Comprehension
- Message Complexity
- Selection of Sensory Modality

Chapter 6. Visual Interfaces
- 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

Chapter 7. Auditory Interfaces
- 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

Chapter 8. Haptic Interfaces
- 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

Chapter 9. Driver Inputs
- General Principles for Driver-DVI Interactions
- Control Placement
- Selecting Physical Control Type
- Control-movement Compatibility
- Control Coding
- Labels for Controls
- Voice Recognition Inputs

Chapter 10. System Integration
- Prioritizing Messages Presented to Drivers
- Using "Master" Warnings in Integrated Warning Systems
- Overview of the HFCV Integration Architecture

Chapter 11. Application of HF Design Principles to Heavy Vehicle DVIs
- Design Considerations for Warning Signals in Heavy Vehicles
- Selection of Sensory Modality for Heavy Vehicle Warnings
- Design Principles for Visual Displays in Heavy Vehicles
- Visual Display Location in Heavy Vehicles
- Design Principles for Auditory Displays in Heavy Vehicles
- Design Principles for Haptic Displays in Heavy Vehicles
- Driver Controls for Collision Warning Systems in Heavy Vehicles
- General DVI Considerations for Heavy Vehicles

Chapter 12. Tutorials
- 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 Vehicles Characteristics and Driving Environment Relevant to DVI Design

Chapter 13. Glossary
Chapter 14. Index
Chapter 15. Abbreviations
Chapter 16. Equations
Chapter 17. Relevant Documents from USDOT, SAE International, ISO
Chapter 18. References

Figure 1. Overview of the Contents of the DVI Design Assistance Document.

In the V2V DVI Design Assistance Document, a consistent two-page format is used to present the individual human factors topics provided in Chapters 3 through 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; supporting design assistance; and a graphic, table, or figure that augments the text information. 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 below in Figure 2:

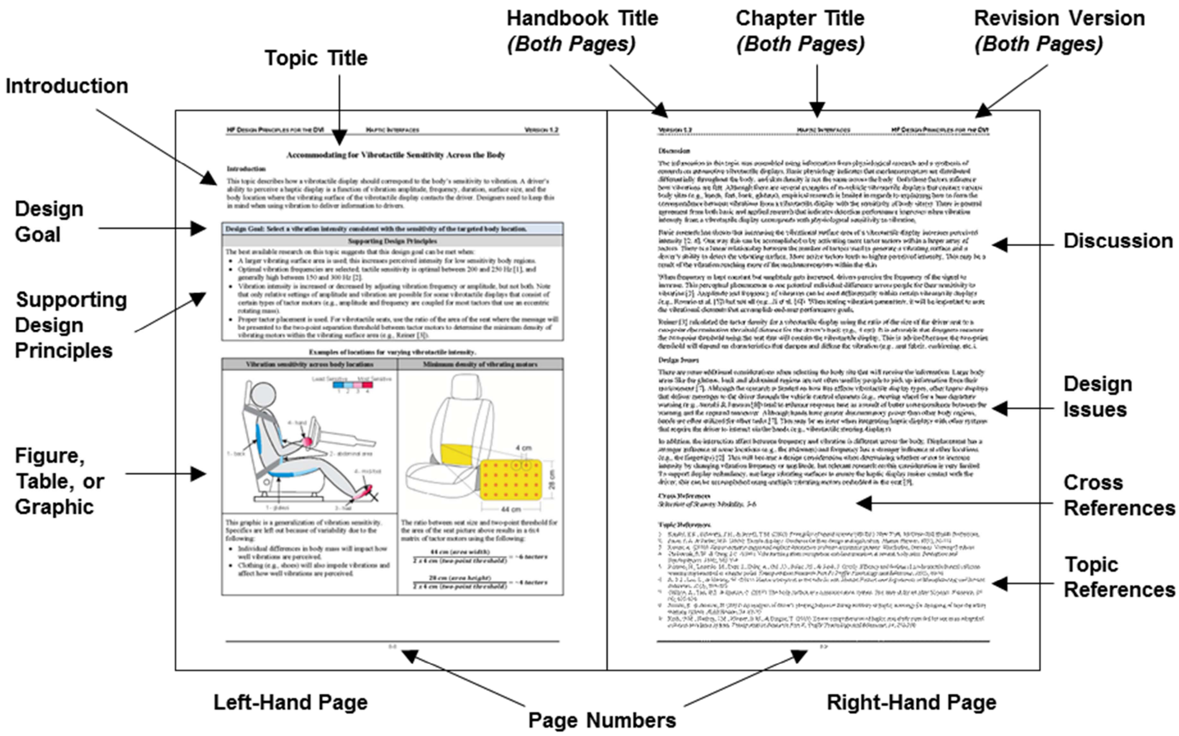


Figure 2. Topic format used in the design assistance document.

Overview of Example Topics

Below, we have summarized the contents from a small sample of the design topics addressed in the DVI Design Assistance Document:

- Locating a Visual Display,
- Perceived Urgency of Auditory Warnings,
- Accommodating for Vibrotactile Sensitivity Across the Body, and
- Selection of Sensory Modality for Heavy Vehicle Warnings

Only 4 of the 52 design topics were included in the interest of the limits of this publication, and these particular 4 topics were chosen due to the expected high interest in them (i.e., they are key topics of interest in current trends for DVI design).

Locating a Visual Display

This topic discusses the issues related to the location of a display where it will be easily seen and comprehended by drivers. As new warning and information systems on the market can increase dashboard complexity, selecting an appropriate location for a visual display is important to minimize information-seeking behavior that distracts from the driving task. Recommended design assistance to facilitate rapid extraction of information while minimizing eyes-off-road glances and negative impacts on driving performance are:

- 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. ISO (1984) recommends that messages that require immediate detection be located within 5 degrees of the forward view when possible. (A).
- Displays are placed in locations that are generally compatible with established expectations or with location cues from other warnings, such as auditory or haptic (B).
- 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 Head-Up Display (HUD) that is used to direct attention to the forward view for critical warnings (C).
- 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; D).

Figure 3 below illustrates potential visual display locations.

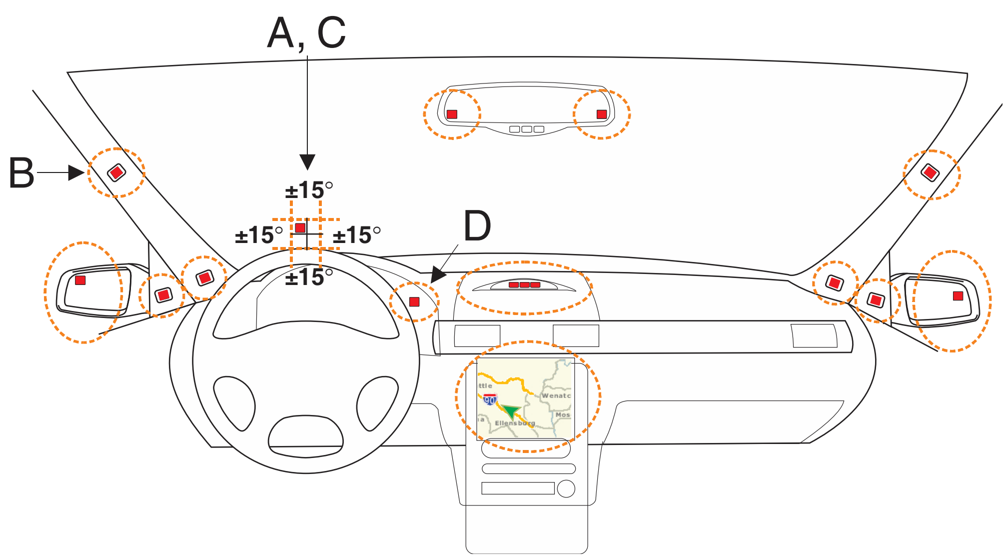


Figure 3. Potential Locations for Visual Displays

Additional discussion in this design topic includes research results and recommendations for keeping warnings near to the driver's line of sight, use of color, and correspondence between the driver's gaze and directional hazard location. Benefits of highly compatible display-response relationships include development of strong mental models by the operator as to how the system works, reduced driver response times, and fewer response errors. Also noted, is the lack of current data or standards regarding messages in heavy vehicle (HV) applications.

Perceived Urgency of Auditory Warnings

This topic discusses and recommends a number of design assistance topics to create auditory warnings that clearly communicate a level of urgency consistent with the urgency of the hazard. Auditory attributes that can be engineered to higher or lower levels of urgency include:

To increase the perceived urgency:

- Use faster auditory signals (e.g., 6 pulse/sec).
- 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., $\geq$1000 Hz).
- Use random or irregular overtones.
- Use a large pitch range (e.g., 9 semitones).
- Use a random pitch contour.
- Use an atonal musical structure (random sequence of pulses).
- Use more urgent words (e.g., “Danger”).

To decrease the perceived urgency:

- Use slower auditory signals (e.g., 1.5 pulse/sec).
- 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).
- Use a regular harmonic series.
- Use a small pitch range (3 semitones).
- Use a down or up pitch contour.
- Use a resolved musical structure (from natural scales).
- Use less urgent words (e.g., “Caution”).

Figure 4 below provides a visual comparison of higher urgency auditory signal characteristics (tops) with lower urgency signal characteristics (bottom).

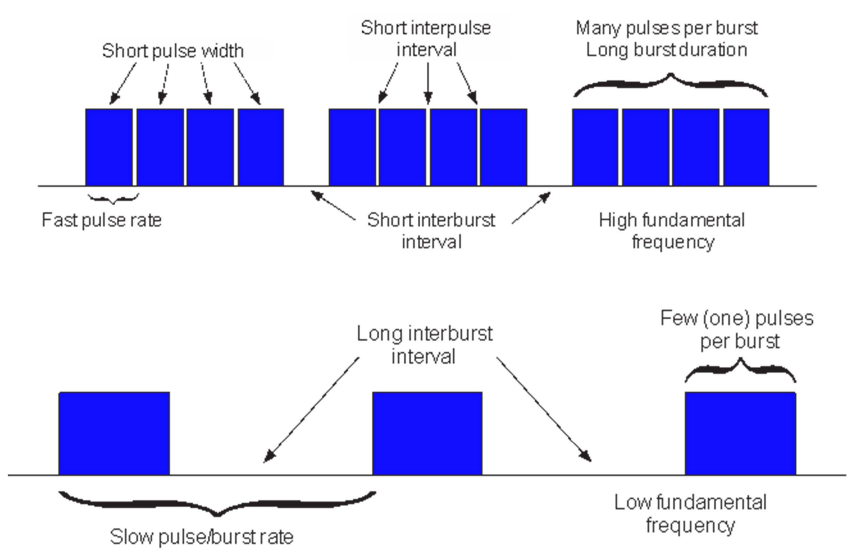


Figure 4. Comparison of Auditory Signal Characteristics Associated with Higher vs. Lower Levels of Perceived Urgency Characteristics

The discussion for this topic includes research results and recommendations indicating that accurate urgency mapping leads to more effective driver response. While more urgent signals are associated with faster reaction times, confusion, startle responses, or distraction can result if the perceived urgency is higher than the situation demands.

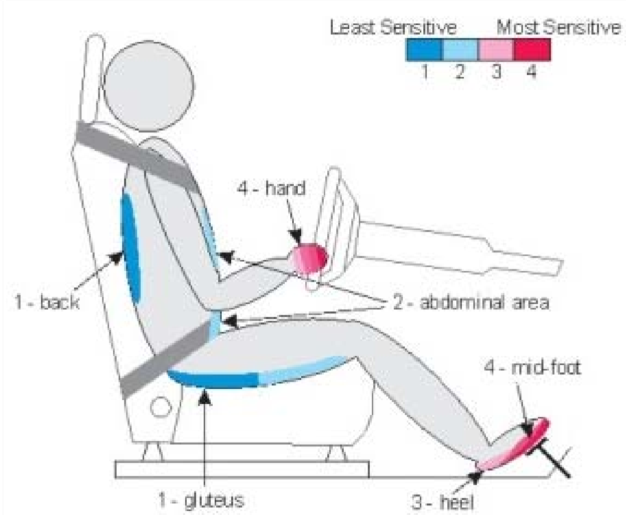
Some of the design trade-offs to be considered include compatibility with other signals, driver annoyance, and distinctiveness of the signal. Message semantics for both signals and speech can affect driver response. Study findings suggest that perceived urgency can be increased using high-urgency semantics (whether with speech or with familiar non-speech signals) into auditory messages that have lower-urgency acoustic characteristics (Guilluame et al. 2002; Baldwin & May, 2011).

Accommodating for Vibrotactile Sensitivity Across the Body

This topic provides design assistance for how to design vibrotactile displays so that they correspond to the body's sensitivity to vibration. Vibrotactile display attributes include vibration amplitude, frequency, duration, surface size, and the body location of the vibrating surface. Displays are most effective when they are readily perceived by the driver thus matching vibrotactile intensity with the differing sensitivity of various body locations will increase detection.

Figure 5 below provides examples of body locations for varying vibrotactile intensity.

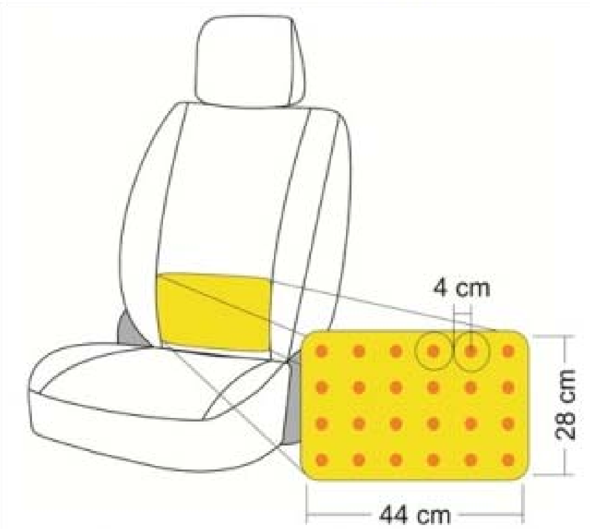
Vibration sensitivity across body locations



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 affect 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 picture above results in a 6x4 matrix of tactor motors using the following:

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

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

Figure 5. General Design Assistance for Vibrotactile Displays

Information on this topic is derived from research on both physiological responses to vibration and vibrotactile message delivery to drivers. As mechanoreceptors are distributed differentially throughout the body, and skin density is not the same across the body, vibrations are felt differently at different body sites. Both basic research and applied research indicate detection of the vibrotactile signal is improved when the vibration intensity corresponds with the physiological sensitivity to vibration.

Generally, drivers perceive increased intensity by either: 1) increasing surface area or number of tactors activated within the surface area, or 2) increasing the amplitude of a constant frequency. A two-point discrimination threshold can be used. Prototype testing using the exact seat to be used with the device is recommended as the threshold will be affected by the fabric, cushioning and other characteristics of the seat.

Additional design issues for consideration include driver familiarity, i.e., most drivers are not used to receiving information via vibrotactile sensation to large body areas such as the gluteus. Using the steering wheel to deliver a haptic cue for lane change warning, for example, would obtain a quicker response due to the correspondence between the warning and the corrective action. Consider also that signals to the hands, while effective sensation-wise, may be less effective when other driver activities using the hands interfere with reception of the signal. Display redundancy can be supported by using larger vibrating surfaces such as the seat.

Selection of Sensory Modality for Heavy Vehicle Warnings

This topic discusses how to select an appropriate presentation, such as visual, auditory, or haptic, for use in a heavy vehicle (HV) environment. The nature of heavy vehicle driving creates additional issues to be considered in light of higher visual scanning demands, the long-term exposure to alerts, and passenger needs. The selected DVI modality should be consistent with HV driver tasks, needs, and expectations. Table 1 below provides a summary of the recommendations for CWS functions and control types. In addition:

- Avoid using exclusively visual warnings for imminent collision warnings.
- Use auditory or haptic signals as the primary mode of conveying collision warning information. 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.
- 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. Design Assistance for Haptic Displays in Heavy Vehicles in the DVI Design Assistance Document provides issues, caveats, and recommendations associated with using haptic signals in heavy vehicles.

Table 1.
Recommendations and Design Assistance for Collision Warning Systems (CWS) in the Heavy Vehicle Cab

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., 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

Most current passenger vehicle CWSs allow disablement of the system by drivers; some current HV CWSs do as well. Disablement of the system, however, defeats the purpose of the fleet owner/operator. Additionally, some research notes that most drivers would not disable the system and prefer an integrated CWS system.

Allowing adjustments to CWS systems can accommodate both owner and driver needs. For example, reducing system sensitivity in a cluttered driving environment would correspondingly reduce the frequency of nuisance alarms, although this may mean a delayed alert which would not provide enough time for response. Another example is the decibel level of alarms, which can cause driver annoyance if set too loud. While research indicates that, for a forward imminent-only crash warning, 87dBA was rated appropriately high by 81% of drivers, 15% did not consider it loud enough (Tidwell et al., in press).

These design assistance topics recommend that HV system sensitivity could be reduced temporarily by drivers to mitigate nuisance/false alarms, through duration and frequency of reduction limits, and based on a standard sensitivity setting using empirical analysis of driver response times and vehicle stopping distances. Minimum audible and luminous settings could employ adaptive capability to accommodate varying levels of ambient noise and nighttime or low luminance conditions.

Involvement of the DVI Design Community

Stakeholder Groups The process for developing the DVI Design Assistance Document included participation of the DVI design community through two stakeholder groups: one for light vehicles and one for heavy vehicles. The stakeholder groups included individuals from OEMs, suppliers, and other industry companies and organizations.

Information Gathering and Sharing When each new organization joins a stakeholder group, the first activity they participate in is a User Requirements Analysis. This activity provides: 1) an opportunity to get a better understanding of the organization's needs as end-users, 2) information on how the DVI Design Assistance Document might fit into the design process at the organization, and 3) a first opportunity for an organization to provide feedback on the general content, format, and organization of the document. Other means of communicating and working with stakeholders was through webinars, workshops, and group or individual interviews.

Feedback and input from the community was used to:

- Support development of the content, format, and organization of the DVI Design Assistance,
- Provide insight into the DVI design process at their organization,
- Evaluate preliminary concepts and plans for the materials,
- Suggest additional research studies and source materials, and
- Review and provide comments on draft materials.

Key questions presented to the stakeholders covered all aspects of the final DVI Design Assistance, were organized around four main topics. Below each of the following topics include some of the main issues discussed:

- What content would you find useful?
    - Key needs for human factors information across a range of in-vehicle issues and applications.
    - Requests for design assistance on specific topics.
    - Data sources that we should use to develop the design assistance.
    - When, where, how, and how often the design assistance would be used.
    - Degree to which initial ideas for content meet the information needs of end-users.
- What format would work best?
    - Overall presentation of the V2V DVI Design Assistance Document – how to best achieve clarity, relevance & ease-of-use.
    - Layout of individual sections or topics.
    - Amount of text vs. non-text elements.
    - Flow and structure of text portions.
    - Use of graphics, figures, and tables.
    - Length and consistency of individual sections or elements.
    - Presentation of constraints and trade-offs.
    - Presentation of supporting materials.
- How would you like to see the information organized?
    - End-user ideas and preferences for overall organization of the materials.
    - Degree to which final organization of the V2V DVI Design Assistance Document:
        - Matches the design process.
        - Matches information needs.
        - Facilitates understanding of the design assistance.
        - Facilitates overall ease-of-use.
- When and how would this information be used within your organization?
    - During initial specification of the driver-vehicle interface
    - During testing and evaluation
    - During a final quality check

CONCLUSIONS

The V2V DVI Design Assistance Document provides a set of 52 human factors design assistance for driver-vehicle interfaces (DVIs) of systems for V2V communication. The design assistance are 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. These design assistance are provided as a tool and a complementary resource to other documents and resources, as well as an expansion to industry research and existing guidance from the National Highway Traffic Safety Administration. The information within this document may be useful to researchers, designers, and original equipment manufacturers and Tier-1 suppliers seeking to ensure that V2V DVIs are designed to better reflect driver limitations and capabilities.

Discussion and Limitations

While DVI design assistance topics such as these can be a valuable tool and resource for designers, they are 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. These design assistance topics are intended to support developers as they design DVIs for V2V communication systems. Note that this document is not meant to serve as a standard or design guideline. 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 V2V DVIs that enable rapid, consistent, and reliable communication between the vehicle and driver.

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