U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

www.nhtsa.gov

DOT HS 810 697 January 2007

Crash Warning System Interfaces: Human Factors Insights and Lessons Learned

Final Report

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
HS 810 697		

4. Title and Subtitle	5. Report Date
Crash Warning System Interfaces: Human Factors Insights and Lessons Learned	January 2007
	6. Performing Organization Code
7. Author(s) John L. Campbell, Christian M. Richard, James L. Brown, Marvin McCallum	8. Performing Organization Report No.
9. Performing Organization Name and Address Battelle Center for Human Performance and Safety 1100 Dexter Avenue N., Suite 1000 Seattle, WA 98109	10. Work Unit No. (TRAIS) 11. Contract or Grant No. TNH22-02-D-02104
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration NVS-331 400 Seventh Street SW. Washington, DC 20590	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The goal of this project has been to develop human factors insights and lessons learned for crash warning devices that emphasize driver performance and safety. The project reflects an important review of the human factors literature associated with the effective implementation of crash warning system interfaces; the lessons learned from this literature were characterized in terms of guidelines for interface design and driver performance. This document is intended to highlight issues to be addressed and provide guidance in the development of Collision Warning Systems (CWSs); the guidelines presented here reflect the best-available human factors information, and are neither requirements nor mandates. Information is presented on a variety of topics relevant to the driver-vehicle interface (DVI) of CWS devices. Chapters 2 through 11 contain the design guidelines produced through this effort. Chapter 2 provides general guidelines for CWS design, and focuses on issues associated with levels of warning and the prioritization of warnings, as well as recommendations for preventing false and nuisance alarms. Chapter 3 provides guidelines for presenting auditory warnings and focuses on the selection and design of various options for auditory warnings, including simple tones, earcons, auditory icons, and speech messages. Chapter 4 provides guidelines for visual warnings, focusing on recommendations for using visual displays and on determining the most appropriate visual display. Chapter 5 provides guidelines for haptic warnings, focusing on recommendations for using haptic displays and on determining the most appropriate haptic warnings. Chapter 6 provides a set of guidelines for selecting and designing user controls for CWS devices. Chapters 7, 8, and 9 provide–respectively–guidelines for forward collision (headway warning), lane change (blind spot warning) and road departure warnings; each of these chapters provides guidance on developing both cautionary and imminent warnings, as well as device-specific guidance for visual, auditory, and haptic warnings. Chapter 10 provides a series of guidelines specific to heavy truck and bus applications.

17. Key Words	18. Distribution Statement
Human Factors, Collision Warning Systems, Driver-Vehicle Interface	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	179	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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List of Acronyms and Abbreviations

AASHTO .... American Association of State Highway and Transportation Officials
ACC .... Adaptive Cruise Control
ACGIH .... American Conference of Governmental Industrial Hygienists
AMR .... Available Maneuvering Room
ANSI .... American National Standards Institute
ASIC .... Application Specific Integrated Circuit
BSW .... Blind Spot Warning
CAMP .... Collision-Avoidance Metric Partnership
CCW .... Cautionary Crash Warning
CDL .... Commercial Driver's License
CMbB .... Crash Mitigation by Braking
CMBS .... Collision Mitigation Braking System
COTR .... Contracting Officer's Technical Representative
CSW .... Curve Speed Warning
CWS .... Collision Warning System
DVI .... Driver Vehicle Interface
EM .... Electromagnetic
FCW .... Forward Collision Warning
FMCSA .... Federal Motor Carrier Safety Administration
FMCW .... Frequency Modulated Continuous Wave
FMVSS .... Federal Motor Vehicle Safety Standards
FOT .... Field Operational Test
FOV .... Field of View
FPD .... Forward Pedestrian Detection
FSK .... Frequency Shift Keying
GES .... General Estimate System
GIS .... Geographic Information System
GPS .... Global Positioning System
GVWR .... Gross Vehicle Weight Rating
HHDD .... High Head-Down Display
HUD .... Head-Up Display

ICAS .... Intersection Collision Avoidance System
ICW .... Imminent Crash Warning
ICNIRP .... International Commission on Non-ionizing Radiation Protection
IEEE .... Institute of Electrical and Electronics Engineers
IP .... Instrument Panel
IR .... Infrared
ISO .... International Organization for Standardization
LCA .... Lane Change Assist
LCW .... Lane Change Warning
LDW .... Lane Departure Warning
LDWS .... Lane Departure Warning System
LED .... Light Emitting Diode
LHDD .... Low Head-Down Display
LIDAR .... Light Detection and Ranging
LTCCS .... Large Truck Crash Causation Study
MMIC .... Monolithic Microwave Integrated Circuit
MT .... Masked Threshold
NHTSA .... National Highway Traffic Safety Administration
OEM .... Original Equipment Manufacturer
OSHA .... Occupational Health and Safety Administration
Radar .... Radio Detection and Ranging
RCA .... Rear Collision Avoidance
RDCW .... Road Departure Collision Warning
RDW .... Road Departure Warning
RT .... Reaction Time(s)
SAE .... Society of Automotive Engineers
SCW .... Side Collision Warning
SGA .... Safe Gap Advisory
SME .... Subject Matter Expert
TTC .... Time-to-Collision
UMTRI .... University of Michigan Transportation Research Institute
WHO .... World Health Organization

CHAPTER 1. HOW TO USE THESE DESIGN GUIDELINES

INTRODUCTION

A comprehensive review and analysis of the human factors research associated with the implementation of crash warning system interfaces has led to the development of these suggested guidelines. These guidelines are intended to be used by anyone responsible for the conceptualization, development, design, testing, or evaluation of in-vehicle crash avoidance systems, especially for forward collision (headway warning), lane change (blind-spot warning), and road departure warnings.

These guidelines reflect an update and a revision of the *Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices* (DTNH22-91-C-07004) developed by COMSIS for the National Highway Traffic Safety Administration (NHTSA) in 1996. The 1996 document presented a set of preliminary guidelines for the human factors aspects of in-vehicle crash avoidance warnings. The intent of this original effort was to develop recommendations for the operation and interface of in-vehicle crash warning devices that would be compatible with drivers' capabilities and limitations.

The goal of the current effort has been to use the intervening 10 years of research to develop human factors guidelines for crash warning devices that emphasize driver performance and safety. Importantly, the project reflects a review of the human factors literature associated with the effective implementation of crash warning system interfaces; this review has led to the development of suggested guidelines that emphasize key human factors insights and lessons learned. This document is intended to highlight issues to be addressed and provide guidance in the development of Collision Warning Systems (CWSs); the guidelines presented herein reflect the best-available human factors information, and are neither requirements nor mandates.

Chapters 2 through 11 contain the design guidelines produced through this effort. Chapter 2 provides general guidelines for CWS design, and focuses on issues associated with levels of warning and the prioritization of warnings, as well as recommendations for preventing false and nuisance alarms. Chapter 3 provides guidelines for presenting **auditory warnings** and focuses on the selection and design of various options for auditory warnings, including simple tones, earcons, auditory icons, and speech messages. Chapter 4 provides guidelines for **visual warnings**, focusing on recommendations for using visual displays and on determining the most appropriate visual display. Chapter 5 provides guidelines for **haptic warnings**, focusing on recommendations for using haptic displays and on determining the most appropriate haptic warnings. Chapter 6 provides a set of guidelines for selecting and designing user **controls** for CWS devices. Chapters 7, 8, and 9 provide–respectively–guidelines for **forward collision** (headway warning), **lane change** (blind-spot warning) and **road departure warnings**; each of these chapters provides guidance on developing both cautionary and imminent warnings, as well as device-specific guidance for visual, auditory, and haptic warnings. Chapter 10 provides a series of guidelines specific to **heavy truck and bus applications**. Chapter 11 provides four tutorials:

- **Applications of CWS Devices**
- **Activation and Operation of CWS Devices**
- **Factors to Consider in Designing CWS Driver Vehicle Interfaces (DVIs) for Heavy Vehicles**
- **Integration of Collision Warnings**

This handbook can be used by individual CWS designers in any number of ways. For example, it can be read through, from start to finish, if one desires an overview of human factors issues, principles, data sources, and guidelines associated with the design of crash avoidance warning systems. Also, individual chapters can be reviewed by designers who would like to focus on specific topics, such as Forward Collision Warning (FCW) systems or Heavy Vehicle applications. Finally, designers may simply refer to specific guidelines, equations, terms, and references as their individual needs warrant. Thus, there is no "right" way to use these guidelines—the day-to-day needs of the individual designer will dictate how and when they should be used.

THE TWO-PAGE FORMAT

In this handbook, a consistent, structured, two-page format is used to present each design guideline. On each page, the main issue (e.g., Desired Characteristics of Auditory Warnings, Design of Imminent Crash Warnings [ICWs], etc.) being addressed by the guideline is indicated by centered bold type within the header. As described in more detail below, the left-hand page presents the title of the guideline; an introduction and overview of the design guideline; the design guideline itself; the rating associated with the guideline; and a graphic, table, or figure that augments the text information. The right-hand page provides a more detailed discussion or rationale for the design guideline that a designer may need in order to perform day-to-day design tasks, as well as special design issues, cross references to other guidelines, and a list of key references. A sample guideline, with key features highlighted, is shown below in Figure 1-1; a detailed description of the presentation format of the guidelines follows.

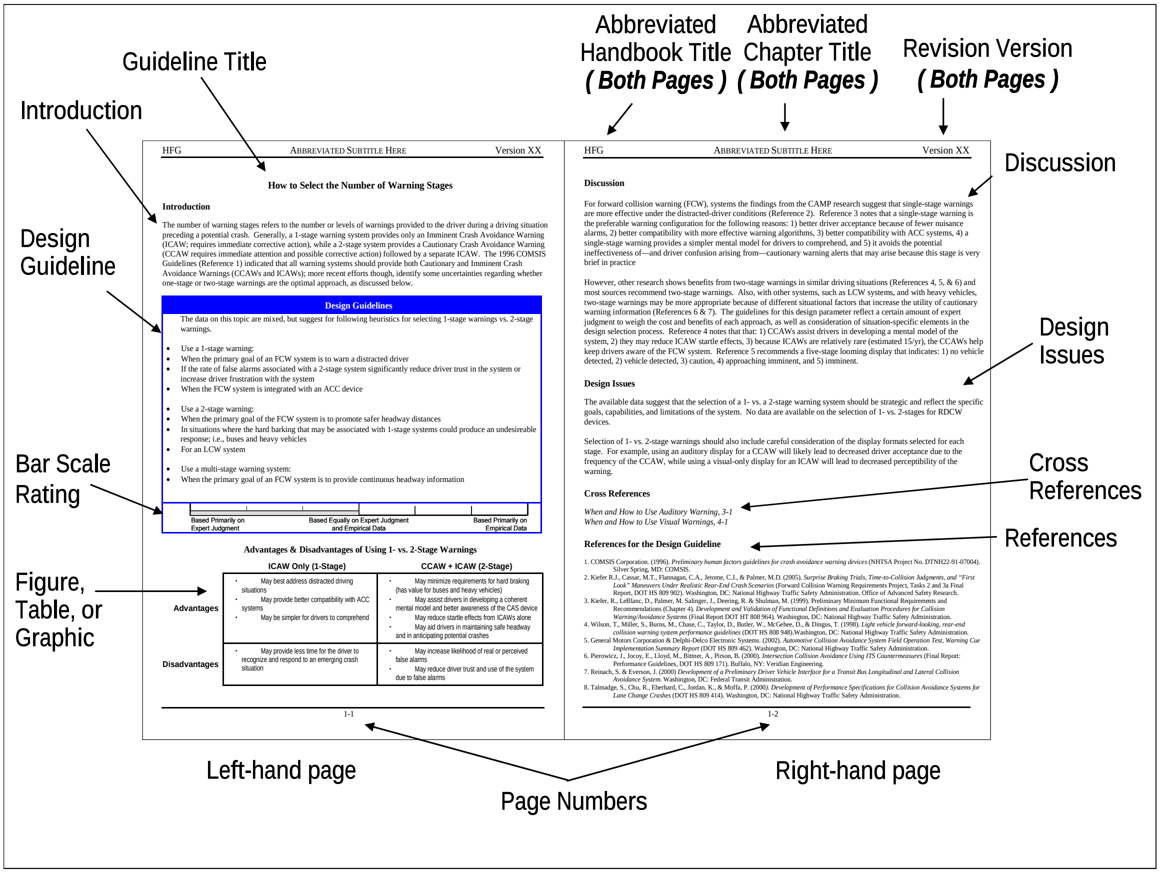


Figure 1-1. Format used in the human factors guidelines for CWS devices

THE LEFT-HAND PAGE

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

Introduction

This subsection briefly defines the design guideline and provides basic information about the design parameter being addressed and the guideline presented. For example, this subsection might provide information that can be used to distinguish this guideline from a related topic or to highlight a special design concept worth considering. This section might also provide the unit of measurement (e.g., decibels, visual angle, meters, foot-lamberts, etc.) for the guideline, or to provide equations for the derivation of certain parameters.

Design Guideline

This subsection presents a quantitative design guideline (when possible), either as a point value, a range, or an explicit recommendation. The design guideline is always presented prominently and is enclosed in a blue box centered on the page.

In some cases, the design guideline is presented qualitatively in general terms (e.g., “Avoid using auditory signals for Cautionary Crash Warning [CCW]”). However, in most cases, the design guideline is presented quantitatively (e.g., “The maximum amplitude of an auditory warning should be no more than 90 dB”).

The Rating System

These guidelines have been developed using the best available evidence. For some design parameters, there are enough empirical data to provide well-supported design guidelines, and the use of expert judgment is minimal. For others, empirical data have only provided the foundation for a decision about what the design guideline should be, but experience and judgment have been used to determine the final design guideline. For yet other topics, there were little or no empirical data available and the design guideline was based primarily on expert judgment.

To aid CWS designers in making design trade-offs, individual design guidelines have been rated according to the relative contribution that empirical data and expert judgment have each made to the design guideline. Specifically, each design guideline has been rated along a continuum, with each guideline falling somewhere between “Based Primarily on Expert Judgment” and “Based Primarily on Experimental Data.” These terms are defined below:

Based Primarily on Expert Judgment. Little or no empirical data were used to develop this design guideline. Expert judgment and design convention were used to develop this design guideline.

Based Equally on Expert Judgment and Experimental Data. Equal amounts of expert judgment and experimental data were used to develop this design guideline. There may have been a lack of consistency in the research finding, requiring greater amounts of expert judgment. Research may have been lacking in this area, requiring the results of research from related content domains to be interpreted for use in this context.

Based Primarily on Experimental Data. Based on high-quality and consistent data sources that apply directly to the guideline. Empirical data from highly relevant content domains (e.g., transportation human factors, field operational tests for CWS concepts) were primarily used to develop this design guideline. Little expert judgment was required to develop this design guideline.

Figure, Table, or Graphic

This subsection provides a figure, table, or graphic to augment the design guideline. This figure, table, or graphic provides “at-a-glance” information considered to be particularly important to the conceptualization and use of the design guideline. It provides a visual representation of the design guideline (or some aspect of the design guideline) that may be difficult to grasp from the design guideline itself, which is quantitative and text-based.

This figure, table, or graphic might take many forms, including: a drawing depicting a generic application of a design guideline or a particular design issue, a flowchart of measurement procedures for the design guideline, a table that summarizes the design guideline, or schematic examples of particular visual warnings.

THE RIGHT-HAND PAGE

Discussion

This subsection briefly summarizes the rationale behind the choice of the design guideline. In particular, the discussion explains the logic, premises, assumptions, and train-of-thought associated with development of the guideline. 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 guideline and to help them explain or justify the design guideline to other members of a CWS development team. Also, since these human factors design guidelines are expected to be revised as additional empirical data become available, this subsection will be useful to future developers of design guidelines. In particular, the discussion will enable future design guideline developers to determine how new human factors information can (or should) be integrated into the existing design guidelines.

For example, the design guideline for "*Determining the Appropriate Auditory Signal*" has been developed through consideration of trade-offs between competing design needs (i.e., the need for the warning to get the driver's attention, the need to avoid annoying sounds, the need to relate the sound to the driving condition). The **Discussion** section for this design parameter reviews research that addresses these trade-offs and makes a "case" for the guideline provided. If new data for reflecting these design considerations are obtained (or if new assumptions are made), future design guideline developers will be able to assess the role and relative importance of these data and determine what (if any) changes should be made to the design guideline.

Design Issues

This subsection presents special design considerations associated with a particular design guideline. These special considerations might include design goals from the perspective of other disciplines (e.g., vehicle interiors, packaging, displays), interactions with other design guidelines, special difficulties associated with the guideline's conceptualization or measurement, or special human performance implications associated with the design guideline.

Cross References

This subsection lists the titles and page numbers of other guidelines within these CWS guidelines that are particularly relevant to the current guideline.

References

This subsection lists the references associated with the formulation of the design guideline. Each of these references will already have been noted within the text of the design guideline (e.g., as part of the discussion included in the introduction, discussion, or design issues sections), and assigned a reference number.

OTHER FEATURES

Equations are numbered sequentially and listed separately in Chapter 12 of this document. A complete reference section is provided in Chapter 14 of this document.

APPLICATION OF THESE GUIDELINES TO HEAVY TRUCKS AND BUSES

Most of the DVI-relevant research on collision warning systems has been conducted on passenger vehicles, not on heavy trucks or buses. Unless otherwise noted, most of the guidelines in Chapters 2 through 9 of this document make reference to empirical studies conducted using passenger vehicles. Many of these guidelines–especially those that reflect basic information processing capabilities and limitations–can be cautiously applied to heavy trucks and buses; this application should reflect careful consideration of the heavy truck/bus environment, as well as other known design constraints. Chapter 10 of this document provides a separate set of guidelines intended for direct application to heavy trucks and buses. Also, Chapter 11 of this document presents an extended tutorial on “Factors to Consider in Designing CWS DVIs for Heavy Vehicles.” This tutorial provides a review of several factors that affect DVI design for heavy trucks and buses, including factors such as vehicle characteristics, operational factors, crash data, driver tasks, and driver workload.

CHAPTER 2. GENERAL GUIDELINES FOR CWS DESIGN

How to Select the Number of Warning Stages

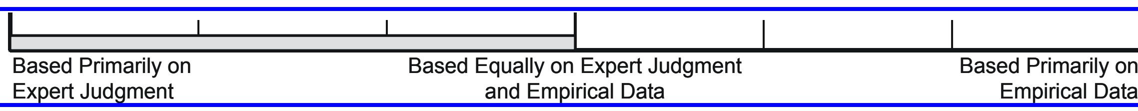
Introduction

The number of warning stages refers to the number or levels of warnings provided to the driver during a driving situation preceding a potential crash. 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. The 1996 COMSIS Guidelines (Reference 1) indicated that all warning systems should provide both CCWs and ICWs. More recent efforts, though, identify some uncertainties regarding whether one- or two-stage warnings are the optimal approach, as discussed below.

Design Guidelines

The data on this topic are mixed, but suggest the following heuristics for selecting one-stage warnings versus two-stage warnings.

- Use a one-stage warning:
  - When the primary goal of a Forward Collision Warning (FCW) system is to warn a distracted driver.
  - 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.
- Use a two-stage warning:
  - When the primary goal of the FCW system is to promote safer headway distances.
  - In situations where the hard braking that may be associated with one-stage systems could produce an undesirable response (i.e., buses and heavy vehicles).
  - For a Lane Change Warning (LCW) system.
- Use a multi-stage (or continuous) warning system:
  - When the primary goal of an FCW system is to provide continuous headway information.



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

	ICW Only (One-Stage)	CCW + ICW (Two-Stage)
Advantages	• May best address distracted-driving situations. • May be simpler for drivers to comprehend.	• 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 increase likelihood of real or perceived false alarms. • May reduce driver trust and use of the system due to false alarms.

Discussion

Most of the available research on this topic has been conducted on FCW systems. This research, as well as relevant LCW and Road Departure Collision Warning (RDCW) research, is summarized below.

For FCW systems, the findings from the Collision-Avoidance Metric Partnership (CAMP) research suggest that single-stage warnings are more effective under the distracted-driver conditions (Reference 2). Reference 3 notes 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) a one-stage warning provides a simpler mental model for drivers to comprehend, and 4) it avoids the potential ineffectiveness of—and driver confusion arising from—cautionary warning alerts because this stage is very brief in practice.

However, other research shows benefits from two-stage warnings in similar driving situations (References 4, 5, and 6) and most sources recommend two-stage warnings. Also, in other situations, such as LCW systems and with heavy vehicles, two-stage warnings may be more appropriate because of different situational factors that increase the utility of cautionary warning information (References 6 and 7). The guidelines for this design parameter reflect a certain amount of expert judgment to weigh the costs and benefits of each approach, as well as consideration of situation-specific elements in the design selection process. Reference 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 (estimated 15 per year), the CCWs help keep drivers aware of the FCW system. Reference 5 recommends a five-stage looming display that indicates: 1) no vehicle detected, 2) vehicle detected, 3) caution, 4) approaching imminent, and 5) imminent.

Design Issues

The available data suggest that the selection of a one- versus two-stage warning system should be strategic and reflect the specific goals, capabilities, and limitations of the system. No data are available on the selection of one- versus two-stage for RDCW devices.

Selection of one- versus two-stage warnings should also include careful consideration of the display formats selected for each stage. For example, using an auditory display for a CCW will likely lead to decreased driver acceptance due to the frequency of the CCW, while using a visual-only display for an ICW will lead to decreased perceptibility of the warning.

Cross References

When to Use Auditory Warnings, 3-2
When to Use Visual Warnings, 4-2

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Kiefer R.J., Cassar, M.T., Flannagan, C.A., Jerome, C.J., and Palmer, M.D. (2005). *Surprise braking trials, time-to-collision judgments, and "first look" maneuvers under realistic rear-end crash scenarios* (Forward Collision Warning Requirements Project, Tasks 2 and 3a Final Report, DOT HS 809 902). Washington, DC: National Highway Traffic Safety Administration, Office of Advanced Safety Research.
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How to Prioritize Multiple Warnings

Introduction

Prioritizing multiple warnings refers to the procedures and heuristics used to determine the relative timing and conveyed urgency of CWS messages that are generated at or near the same time.

Design Guidelines

- CWS warnings, whether they are ICW or CCW, should have priority over all other in-vehicle messages.
- When determining priority among multiple collision warnings, the following procedures should be used (adapted from Reference 1, refer to this data source for additional details):

Prepare to Prioritize Messages

- Identify at least 5 examiners to conduct the evaluations.
- Identify and assemble messages that are to be prioritized.
- For each message, describe the driving scenario (i.e., context, conditions, and situation associated with the message). This might include trip type, roadway type, speed, weather, traffic situation, vehicle type, vehicle condition (note that if the same message could be presented in more than one condition/situation, it should be prioritized separately for each condition/situation).

↓

Select Desired Weights for Criticality and Urgency

- Assign relative weights, k_c and k_u to, respectively, the criticality and urgency criteria. Selecting, for example, a 1 for each of these values would mean that the contribution of criticality and urgency to final priority values would be the same. Selecting a 1 for k_c and a 2 for k_u would mean that urgency was given twice the weight as criticality. Common weights can be selected for the entire evaluation, or individual evaluators can select their own weights, though the final priority calculations will become more complex if this is done.

↓

Evaluate Criticality and Urgency for each Message

- Assess risk to vehicle, occupants, and/or pedestrians using the following four-point scale for criticality: 3 = severe or fatal injury, 2 = injury or possible injury, 1 = no injury (vehicle damage), 0 = no injury (no vehicle damage).
- Assess the urgency of the situation using the following four-point scale: 3 = immediate response required (0-3 seconds), 2 = response required within 3-10 seconds, 1 = response preparation needed, action needed between 10 and 120 seconds, 0 = information only, no direct action required by the driver.

↓

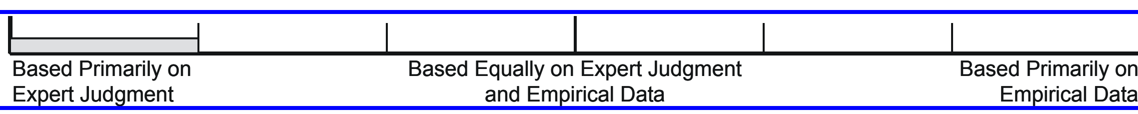
Calculate Priorities Among CWS Messages

- For each message, calculate the priorities assigned by individual evaluators:
  $p_{ij} = k_c c_{ij} + k_u u_{ij}$ (1)
  where:
  p_{ij} = the priority value for an individual message from an individual evaluator
  c_{ij} , u_{ij} = individual scores for, respectively, criticality and urgency
  k_c, k_u = individual weights for, respectively, criticality and urgency
- For each message, calculate the average priority value across evaluators.

↓

Develop Prioritized List of CWS Messages

- Before finalizing the priorities, verify that there was sufficient agreement across the evaluators to be confident of the quality of the data. For example, check to see if at least half of the evaluators agreed on the criticality and urgency of individual messages or calculate the standard deviation of the priority values across evaluators and verify that the standard deviation is less than 1.0.
- If confidence in the data is low, make sure common procedures and heuristics were used across the evaluators and either adjust scores by consensus or repeat Steps 2-4 above until adequate confidence in the data is achieved.
- Once adequate confidence in the data is achieved, rank order the messages from highest to lowest priority value; when items have the same priority values, the message with the highest criticality score should have a higher priority.



Discussion

Multiple sources within the human factors and cognitive psychology literature describe the information processing bottlenecks and decrements in performance associated with perceiving, processing, and responding to more than one stimulus simultaneously (see also Reference 2). Although these decrements are greatest when the stimuli are presented via the same perceptual modality (e.g., two visual messages or two sounds), interference and performance decrements can also occur with simultaneous or near-simultaneous presentation of messages using different modalities. Given the safety-relevance of collision warnings, it is important to emphasize the priority of collision warnings over non-collision warnings, and to identify procedures for prioritizing collision warnings from different systems (e.g., forward collision versus lane change versus road departures) and from different stages within the same system (e.g., ICW versus CCW).

Reference 3 recommends that: 1) multiple crash avoidance warnings occurring simultaneously automatically be prioritized in terms of their severity and urgency, 2) only the highest priority crash warning be presented in the auditory or tactile modality, 3) all crash avoidance warnings be presented simultaneously in the visual modality, 4) ICW messages have priority over CCW messages, 5) target-specific warnings (e.g., a car in the vehicle path has been sensed) have priority over non-target-specific warnings (e.g., road friction is low), and 6) crash avoidance warnings should take precedence over all other in-vehicle warnings.

A recently-developed International Organization for Standardization (ISO) standard (Reference 1) for prioritizing messages provides two different procedures for determining the relative priority of all in-vehicle messages based on assessed criticality and urgency. In the first method ("Priority Index Method"), expert evaluators rate both criticality and urgency on a 0-3 scale and develop a priority index for each message based on weighted criticality and urgency factors. In the second method ("Priority Matrix Method"), expert evaluators make pairwise comparisons among all possible pairs of messages, determining which of the two messages should receive priority, or whether the messages should have the same priority.

The guidelines above generally reflect the procedures suggested for the Priority Index Method from Reference 1. While this procedure may provide results similar to the recommendations from Reference 3 (and perhaps from using the simpler Priority Matrix Method as well), it is more systematic and rigorous and seems better suited to determining priority among multiple CWS messages.

Design Issues

This design guideline also can be used to prioritize messages from navigation devices and common messages from sensors such as oil pressure and engine temperature. It is unclear, however, if "messages" from entertainment systems should be included among the messages to be prioritized, and if entertainment systems must be muted prior to the presentation of a collision warning. Although no performance data are available to address this issue, References 3 and 4, among others, recommend that entertainment systems should be muted in advance of auditory collision warnings as long as the system processing time necessary to perform this action does not significantly delay the presentation of the warning to the driver.

Reference 3 recommends that all crash warnings, regardless of priority, should be presented simultaneously in the visual modality. No data source is cited supporting this recommendation and the best available evidence suggests that the simultaneous presentation of multiple visual warnings will be confusing to drivers and, possibly, interfere with the driver's response to the highest priority warning. Also unclear from the literature is how much time to allow between warnings for simultaneous or near-simultaneous collision conditions. In order to avoid confusions and interference with the driver's response to the highest priority auditory warning, subsequent auditory warnings should not be presented until the emergency condition that generated the higher priority warning no longer triggers a warning.

Cross References

How to Integrate Warning Systems, 2-6

References for the Design Guideline

1. International Organization for Standardization (ISO). (2004). *Road vehicles – Ergonomic aspects of transport information and control systems (TICS) – Procedures for determining priority of on-board messages presented to drivers* (ISO 16951). Geneva, Switzerland.
2. Wickens, C.D. (1992). *Engineering Psychology and Human Performance* (2nd ed.). New York: HarperCollins Publishers.
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How to Integrate Warning Systems

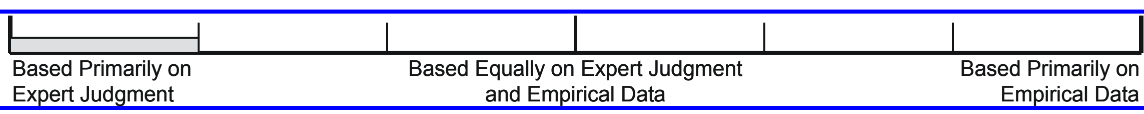
Introduction

Warning integration refers to the merging of individual CWS components into a comprehensive, interoperable system. The 1996 COMSIS Guidelines (Reference 1) provided some general guidance relevant to this topic (see below). This guidance, though, was unsourced and not specifically focused on the CWS devices included in the current guidelines. As seen below, there is very little directly applicable data that can be used to develop specific, comprehensive guidance for the integration of collision warnings. These guidelines include relevant design principles, but primarily seek to identify broader issues and questions that designers should consider when seeking to integrate collision warnings from multiple CWS devices.

Design Guidelines

There is very little directly applicable data that can be used to develop specific, comprehensive guidance for the integration of collision warnings; the data that are available are not entirely consistent. However, the following topics should be considered when integrating multiple CWS devices within the in-vehicle environment:

- **Prioritizing** in-vehicle information is a key aspect of CWS integration (see also *How to Prioritize Multiple Warnings, 2-2).*
- **Physical Integration** of collision warnings will include decisions about whether to use a centralized display to present visual warnings associated with two or more CWS devices or to use distributed displays. Physical integration might also include decisions about whether the controls associated with a CWS device or devices (e.g., on/off, warning intensity, warning sensitivity) are co-located in a single interface or separated.
- Determining how to present warnings from **simultaneous hazards** (e.g., forward collision plus a potential side object collision) is a crucial design question that has not been satisfactorily answered by the literature. Key questions include:
    - Should simultaneous warnings, corresponding to simultaneous hazards, ever be presented, or should the highest priority hazard be cleared before a warning before the second highest priority hazard is presented?
    - If simultaneous warnings are presented, what modalities should be used; the limited available data suggest that the driver should be warned about the highest priority hazard with an auditory tone and that warnings for lower priority hazards occurring at the same time should be presented visually. Should simultaneous or near-simultaneous auditory warnings ever be presented; how much time should separate near-simultaneous auditory warnings?
    - With an integrated system, should individual hazards be combined (in terms of priorities and subsequent presentation of warnings) in a way that leads to a summation of warnings; for example, should multiple CCWs "add up" to an ICW?
- What, if any, might be the role of **active vehicle control** under simultaneous hazard conditions? Is an automated system that makes vehicle control decisions and acts on them (e.g., automatic braking) an appropriate method to use for preventing or mitigating crashes? If CWS devices were to include such automated functions, what rules should be used to allocate functions between the system and the driver?
- Complete **CWS integration** can occur at the software, hardware, and component level. Thus, for CWS devices, "integration" is a design activity that occurs at much more than just the DVI. If integration of multiple CWS devices takes place, this integration will likely need to occur at the sensor, vehicle information processing, warning algorithm, vehicle component, and DVI levels.



Discussion

The timing, modality, location, and format associated with presenting warnings from multiple CWS devices are key aspects of the warning integration topic. Little directly-relevant research has been conducted in this area. The 1996 COMSIS Guidelines (Reference 1) provided the following general rules for the display of multiple, simultaneous collision warnings: 1) all crash avoidance warnings, regardless of their priority, should be presented simultaneously by means of a visual display, 2) only the highest priority warning in effect should be presented by means of an acoustic or tactile display, 3) when auditory or tactile displays are used, a clearly distinguishable cue should be provided to the driver between the termination of the highest priority imminent warning and initiation of the next highest priority warning. In the case of directional warnings the directional nature of the warning indication is sufficient to provide this cue.

Reference 1 also notes, more generally, that the display of multiple warnings should prevent the driver from being overwhelmed with information and warnings, yet should provide the driver with sufficient information to assess the hazard situation. Though unsourced, these principles have not been refuted by any subsequent empirical data.

Reference 2 provides a comprehensive summary of warning redundancies and suggests that perhaps a master alerting signal–probably auditory, with localization cues to distinguish directionality–should be incorporated into multi-functional CWSs. They note that a speech signal (e.g., "Danger") may be the only signal that the driver has time to perceive and respond to.

Reference 3 provides a literature review that discusses some of the key challenges and issues relating to the concurrent presentation of warnings from multiple CWS devices and presents the results of driving simulator studies. These studies indicated that presenting warnings from different systems separately yields better responses to front and side hazard events that occur in close temporal proximity. In particular, a configuration that contained distinct and localized auditory and visual warnings for FCW and LCW systems (distributed system) was more effective than a single warning system that presented the same visual and auditory warning for both hazard events (centralized system). Also, drivers were more likely to notice the second auditory warning with the distributed system than with the centralized system. An additional finding was that the visual warnings may not be necessary because drivers failed to notice these warnings in either the distributed or centralized configurations. Reference 3 reported that a single universal warning tone, repeated more than once to indicate more than one kind of hazard, was not as effective as using different tones. When the universal tone was used, drivers tended to misinterpret the second signal, perhaps believing that it was a continuation of the first signal.

In Reference 4, a simulator study was conducted on the impact of non-CWS notifications on driver responses to collision warnings. This research found that low priority warnings presented 0.3 to 1.0 seconds before a collision warning can interfere with driver responses to the collision warning. In Reference 5, a simulator study was used to investigate how driver performance and preference were affected by presentation of a single master auditory alert versus multiple individual alerts. Forward and rear collisions and lane departures were studied. Although drivers preferred the multiple individual alerts, performance was the same with both kinds of alerting approaches. Simultaneous collision events were not studied.

Design Issues

Some of the key challenges involved with using multiple warning systems (from Reference 3) are that: 1) multiple warnings can be problematic if they create an atmosphere in which drivers are unsure about or misjudge the meaning of a particular warning (i.e., driver confusion), and 2) by overloading drivers in situations where multiple warnings are issued simultaneously or in close temporal succession (induced information overload).

Cross References

How to Prioritize Multiple Warnings, 2-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. International Organization for Standardization (ISO). (2005). *Road vehicles – Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems* (ISO/TR 16532). Geneva, Switzerland: International Organization of Standards.
3. Chiang, D., Brooks, A., and Llaneras, E. (2004). *Final Task Report: Investigation of Multiple Collision Alarm Interference Driving Simulator Study* (Report for the National Highway Traffic Safety Administration). Torrance, CA: Dynamic Research.
4. Wiese, E.E. and Lee, J.D. (2004). Auditory alerts for in-vehicle information systems: The effects of temporal conflict and sound parameters on driver attitudes and performance. *Ergonomics*, *47*, 965-986.
5. Ho, A.W.L., Cummings, M.L., Wang, E., Tijerina, L., and Kochlar, D.S. (2006). Integrating intelligent driver warning systems: Effects of multiple alarms and distraction on driver performance [CD-ROM]. *Proceedings of the 2006 Annual Meeting of the Transportation Research Board*.

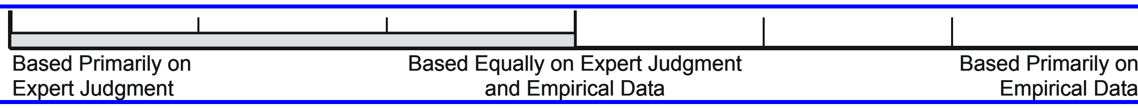
How to Make Warnings Compatible with Driver Responses

Introduction

Making warnings compatible with driver responses refers to the importance of designing warnings that elicit a response from the driver that is consistent with the actions needed to properly respond to the driving situation. The 1996 COMSIS Guidelines (Reference 1) provided a general principle stating that warnings should be presented in a manner that is compatible with the driver's desired vehicle control response. There have been few data sources published since 1996 that directly address the issue of response compatibility. As seen in the table below, the human factors principle of "compatibility" is broader than just the topic of warnings.

Design Guidelines

- Warnings should: 1) be presented in a manner that is compatible with the driver's desired vehicle control response, 2) induce an orienting response, where appropriate, causing the driver to look in the direction of the hazard, and 3) adequately capture the driver's attention without startling the driver (adapted from Reference 1).
- Before attempting to link warnings with a specific driver response, designers should be:
  - Confident that the CWS device (i.e., sensors, processors, DVI) is capable of determining the desired driver response with very high levels of accuracy and reliability.
  - Clear as to what kind of response (i.e., a perceptual response—looking in the direction of the hazard, or a motor response—braking or turning away from a hazard) the warning is intended to elicit.
  - Confident that the warning will indeed elicit the desired driver response under most driving situations and conditions.



Examples of key compatibility types

Conceptual Compatibility	Spatial Compatibility
• Iconic or graphical representations of desired driver control actions, such as using an icon of a STOP sign to communicate the need to brake. • Looming displays to communicate relative headway. • The use of the color green to indicate "OK" or "Go." • The use of the color red to indicate "not OK" or "Stop." • The use of the color yellow to indicate "Caution."	• Visual LCWs located on the A-pillars or side mirrors, corresponding to side of the vehicle associated with the hazard. • Auditory LCWs presented directionally via either the right- or left-side speakers, corresponding to side of the vehicle associated with the hazard. • Haptic RDCWs presented through seat vibrations on either the left or right side of the driver's seat pan, corresponding to side of the vehicle associated with the hazard. • Haptic FCWs that take the form of a brake pulse, informing the driver of a need to brake in order to avoid a hazard. • Haptic LCWs or RDCWs presented as steering wheel torque in the direction away from the hazard.

Discussion

The COMSIS Guidelines (Reference 1) noted that the warning should induce an orienting response that is compatible with the desired driver action, and 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 (Reference 2) than do 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.

Examples of collision warnings that might be intended to induce high levels of display-response compatibility are directional auditory warnings that orient the driver's perceptual and motor response to the direction of the hazard, and brake pulse warnings (when used as a haptic warning) that can alert the driver of the need to brake as a response to a potential crash. Some key concerns, though, in designing warnings that will elicit the desirable response from the driver by virtue of key warning characteristics are: 1) knowing enough about the unfolding crash situation to know what driver response is most desirable, 2) designing a warning that distinguishes between a desirable perceptual response (looking in the direction of the hazard) and a desirable motor response (braking or turning away from a hazard), and 3) being able to effectively communicate the most desirable response via the DVI.

In Reference 3, a driving simulator was used to compare haptic and auditory warnings for a simulated lane departure system. Although a pulsed steering torque often led to a steering response in the wrong direction (it was often interpreted by subjects as a wind gust) a steering vibration led to correct interpretation and performance by subjects.

Design Issues

High false-alarm rates can be expected to reduce the utility of even those displays that are highly compatible with their associated driver responses.

In the absence of compelling data, care should be taken to avoid assuming that compatible relationships exist between displays and their desired responses. Such relationships are not always obvious, widespread, or equally strong, and there are some circumstances in which the application of design trade-offs might suggest that display-response compatibility be avoided in order to accrue some other benefit or advantage.

Cross References

Specific Guidelines for Design of CWS Controls, 6-10

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Wickens, C.D. (1992). *Engineering Psychology and Human Performance* (2nd ed.). New York: HarperCollins Publishers.
3. Suzuki, K. and Jansson, H. (2003). An analysis of driver's steering behaviour during auditory or haptic warnings for the designing of lane departure warning system. *JSAE Review, 24*(1), 65-70.

How to Prevent False or Nuisance Warnings

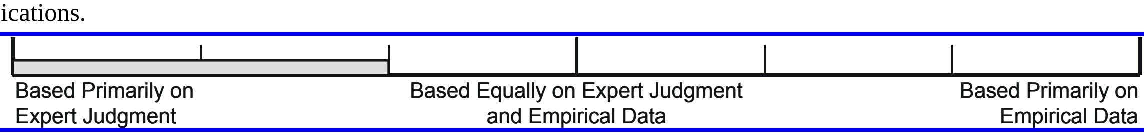
Introduction

False alarms or warnings refer to those CWS alerts that are triggered in the absence of an appropriate stimulus. For example, a false alarm occurs when the system provides a FCW when there are no cars in front of the driver's vehicle, or provides one based on an out-of-path vehicle or roadside object such as a guardrail or a lightpost. Nuisance warnings include a subjective component. They refer to warnings that are caused by an appropriate stimulus, but are perceived by the driver to be inappropriate due to some aspect of their implementation such as their frequency, timing, intensity, or modality.

Design Guidelines

- For FCW devices, ICW false alarms should be limited to less than one per week for in-path and one per week for out-of-path alarms.
- For FCW devices, CCWs should not be presented via the auditory or haptic modality, in order to mitigate driver annoyance with nuisance CCWs.
- For LCW devices, drivers are less likely to consider even relatively high rates of "nuisance" alarms annoying, as long as the warnings are unobtrusive and presented via the visual modality only.
- From References 1 and 2, key 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 the 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 the annoyance of false/nuisance warnings 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).
- Other strategies include integrating the CWS device into:
    1. A larger sensor suite that determines whether or not a driver has already begun to initiate a crash avoidance maneuver (by steering away, releasing the accelerator, or braking) and then use this information to decide whether or not to initiate a warning.
    2. A Global Positioning System (GPS) tied to a Geographic Information System (GIS) that can use adjacent roadway information to improve the percentage of "True Positive" alerts.

Note: The topic of false/nuisance alarms has not been studied for heavy vehicles or buses. While these guidelines probably reflect the "best available" evidence for heavy vehicles/buses, they should be used cautiously in these applications.



Four performance outcomes from CWS devices

	Situation Warrants Warning the Driver	Situation Does NOT Warrant Warning the Driver
Warning Provided to the Driver	True Positive (hit)	False Positive (either a false alarm or a nuisance alarm)
No Warning Provided to the Driver	False Negative (miss)	True Negative

Adapted from Reference 3

Discussion

CWS design reflects a balance between a system that provides warnings that are perceived to be generally valid and useful by most drivers, and one that provides too many warnings that are either false or are perceived to be unnecessary. Identifying specific false/nuisance alarm rates consistent with this balance has been a challenge for CWS development because an ideal false/nuisance alarm rate will necessarily reflect a cost/benefit judgment associated with the CWS device as a whole. That is, drivers will view false/nuisance alarms to be one of the costs associated with a system that can also provide them with important safety benefits. Very little of the research conducted to date has been able to replicate the conditions necessary for drivers to fully recognize the benefits associated with a particular CWS device and, therefore, little can be confidently concluded regarding drivers' precise willingness to tolerate the inevitable presentation of false/nuisance alarms.

The recommended false-alarm rate of less than one per week for FCW ICWs is consistent with the value recommended in Reference 3. In a CWS study reported in Reference 4, a majority of alerts were perceived to have been either unnecessary or a nuisance, fostering poor driver acceptance and trust. In this study, only 27 percent of all imminent alerts were "true positives." Since drivers became aware that the FCW alerts often occurred in situations in which braking was not required, they did not brake reflexively to imminent FCW alerts. Reference 4 does not identify or recommend acceptable false-alarm rates as a function of exposure (e.g., false-alarm rate per 100 miles traveled). Reference 5 provides information on the conceptualization of an Intersection Collision Avoidance System (ICAS). Relying on engineering judgment, this data source recommended that false alarms should not exceed 10 percent. There are no clear data on what an acceptable false-alarm rate is for FCW CCWs; however, both References 3 and 4 note that CCW false alarms due to premature warning timing may be addressed by allowing drivers to adjust the sensitivity or timing of the warning, or to turn off the CCW completely. Reference 6 examined false-alarm rates in LCW systems and found that drivers did not consider the relatively high rate of false alarms (42 per hour) as annoying, likely because the alarms were unobtrusive and visual, and most 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).

The key guideline for this topic from Reference 1 was essentially to minimize the false alarms that the driver would experience through implementation of some of the four strategies presented above. A number of other reference sources cited and recommended these same strategies or suggested similar strategies. Reference 7 noted that the number of nuisance alarms could be reduced by integrating a CWS device into a larger sensor suite that determines whether or not a driver has already begun to initiate a crash avoidance maneuver and then uses this information to decide whether or not to initiate a warning. Reference 2 provided four concepts for minimizing the occurrence of false alarms: 1) use a graded sequence of warnings, 2) change modality as the severity of the situation increases (e.g., warn first visually, then add auditory component as severity increases), 3) individualize warnings (i.e., make some settings driver adjustable), and 4) present headway displays as initial status devices that expand to provide warnings as needed. Some of these concepts, however, may reflect the type of CWS device being implemented or the type of vehicle being fitted with the device. For example, changes in modality may be more appropriate for LCW systems than for FCW systems, and a graded sequence of warnings may be more appropriate for commercial vehicles than for passenger vehicles.

Design Issues

With regard to the combined effect of false alarms from multiple devices, this issue has not been specifically addressed in any of the reviewed research sources. However, Reference 8 notes that the effects of false-alarm rates are further complicated when multiple CWS devices (e.g., capable of presenting both FCWs and LCWs) are implemented. Also, there is some evidence (Reference 9) that false alarms presented via speech displays will be associated with greater levels of driver annoyance than false alarms presented using tones.

Cross References

Design of ICWs for FCW Systems, 7-2
Design of CCWs for FCW Systems, 7-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Horowitz, A.D. and Dingus, T.A. (1992). Warning signal design: A key human factors issue in an in-vehicle front-to-rear-end collision warning system. *Proceedings of the Human Factors Society 36th Annual Meeting*, 1011-1013.
3. Kiefer, R., LeBlanc, D., Palmer, M. Salinger, J., Deering, R. and Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (Final Report DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.
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5. Lee, S.E., Knipling, R.R., DeHart, M.C., Perez, M.A., Holbrook, G.T., Brown, S.B., et al. (2004). *Vehicle-Based Countermeasures for Signal and Stop Sign Violations: Task 1. Intersection Control Violation Crash Analyses, Task 2. Top-Level system and Human Factors Requirements* (DOT HS 809 716). Washington, DC: National Highway Traffic Safety Administration.
6. Talmadge, S., Chu, R., Eberhard, C., Jordan, K., and Moffa, P. (2000). *Development of performance specifications for collision avoidance systems for lane change crashes* (DOT HS 809 414). Washington, DC: National Highway Traffic Safety Administration.
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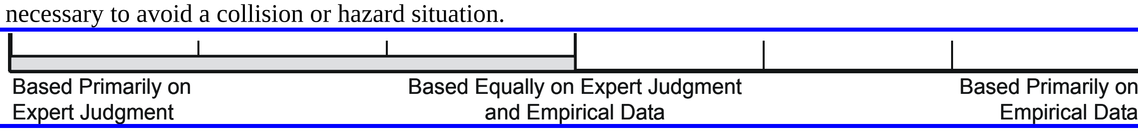
Warning Timing

Introduction

Warning timing refers to temporal characteristics of collision warning presentation, relative to the potential hazard or conflict. It generally refers to the necessary underlying conditions for triggering crash alerts. The COMSIS (1996) guidelines primarily cover warning timing in the context of specific collision warning devices (Reference 1). The current guideline provides more general information about warning timing, especially regarding key elements of driver performance.

Design Guidelines

- Warning timing for forward-acting CWSs such as FCW and Curve Speed Warning (CSW) systems should take into account expected driver response time and driver-selected deceleration levels.
- Warning timing for side-acting CWSs such as LCW and Lane Departure Warning (LDW) systems should be based primarily on when the system detects the driver's intent to change lanes or on when it predicts a lane departure/conflict with a side hazard.
- Sensitivity settings may be provided that modify the baseline warning timing according to driver preference. However, these adjustments should be bounded by a minimum warning time that is based on kinematic conditions necessary to avoid a collision or hazard situation.



The table below shows actual "last-second" driver deceleration levels (in g's) observed under different conditions, including brake instructions, travel speed, and lead vehicle deceleration level. In the study described in Reference 2, drivers were distracted by in-vehicle tasks (e.g., looking at the instrument panel). Note that the "Normal" braking instruction condition represents aggressive normal braking because the task was a "last second" braking maneuver. Also, in the "Stationary" lead vehicle deceleration condition, the subject vehicle encountered an unexpected stopped lead vehicle.

Observed Deceleration Levels (in g's) for Braking Instructions, Travel Speed, and Lead Vehicle Deceleration

	Average Actual Deceleration											
	Subject Vehicle Speed at 30 MPH				Subject Vehicle Speed at 45 MPH				Subject Vehicle Speed at 60 MPH			
Lead Vehicle Decel. Level (in g's)	**.15**	**.28**	**.39**	**Stationary**	**.15**	**.28**	**.39**	**Stationary**	**.15**	**.28**	**.39**	**Stationary**
Braking Instruction												
Normal	.15	.26	.32	.21	.21	.30	.36	.25	.21	.32	.41	.28
Comfortable Hard	.28	.39	.43	.34	.27	.43	.49	.40	.26	.45	.53	.44
Hard	.25	.40	.44	.35	.28	.40	.44	.41	.25	.47	.54	.45

Table adapted from Reference 2

Discussion

Forward-acting systems: FCW and CSW systems require drivers to slow or stop their vehicles with enough time to avoid the hazardous situation. These actions require two driver-controlled components that should be included as part of any warning timing algorithm. These include: 1) a driver response time that determines how much time passes before the vehicle starts to decelerate, and 2) a driver-initiated deceleration level that determines how long it takes for the vehicle to stop (Reference 2).

Reference 3 provides a meta-analysis of driver perception-brake reaction times (RTs) under different conditions. Drivers that are fully expecting a hazard have an estimated median brake RT of 0.6 to 0.65 seconds. Drivers responding to unexpected but common hazards such as brake lights have an estimated median brake RT of 1.15 seconds, while drivers responding to complete surprise events have an estimated median brake RT of 1.4 seconds. Urgency (e.g., low Time-to-Collision (TTC)) can lead to faster RTs, however, there is a high degree of variability regarding the magnitude of the RT decrease (e.g., 0.1 to 1 second improvement). The CAMP driver interface studies (Reference 2) found that distracted drivers responding to surprise braking events had an 85th percentile brake RT of 1.18 seconds and a 95th percentile brake RT of 1.52 seconds. With regard to CSW systems, Reference 4 provides information about driver response times for last-second steering maneuvers (e.g., from straight-away to curve) under best-case assumptions (e.g., fully alert driver expecting the curve). In this study, drivers approaching a wall that required a 3, 5, or 7 degree course correction to avoid a wall barrier initiated steering corrections approximately 1.9 to 2.5 seconds (median values) before the time of impact with the wall.

With regards to deceleration level, the table on the previous page shows "last-second" actual driver deceleration levels observed under different conditions, including brake instructions (aggressive normal, comfortable hard, and hard), travel speed (30, 45, and 60 mph), and lead vehicle deceleration level (0.15g, 0.28g, 0.39g, and lead vehicle stationary). Note that warning timing for the FCW system in Reference 2 was actually based on *required* deceleration level rather than actual deceleration level (the system used the 50th percentile "hard braking" required deceleration). The required deceleration is the deceleration level that the subject vehicle must have in order to come to a complete stop exactly at the hazard (e.g., lead vehicle's rear bumper). Required deceleration is typically less than the actual deceleration (shown in table), which is the deceleration level that drivers actually use when stopping and which brings them to a stop at some point before the hazard distance (i.e., with a stopping margin). Required deceleration was used because it was found to be more balanced (e.g., not overly aggressive and not too under-aggressive).

Reference 2 also suggests that required and actual deceleration measures appear to be more useful for determining crash alert timing than time-based measures (e.g., TTC or time-headway). The reasons for this are that 1) deceleration measures are tightly coupled with fundamental kinematic aspects of the situation while time-based measures are not, and 2) the deceleration measures (especially required deceleration) are significantly more stable across kinematic conditions than time-based measures.

Side-acting systems: Warning timing for LCW and LDW systems should primarily be based on when the system detects the driver's intent to change lanes or on when it predicts a lane departure/conflict with a side hazard. Currently, no reports recommend basing warning timing on alternative driver-based measures such as reaction time or time required to make steering corrections, however, the LDW system in Reference 5 incorporated a sensitivity-setting-based time element in warning timing.

Sensitivity Settings: Providing limited control of warning timing via sensitivity settings can allow drivers to customize warning timing to match their driving preferences and reduce nuisance alarms. In Reference 5, drivers tried out different settings for the first week or so then settled in on a single setting for most of the remaining test time. This led to overall positive driver impressions of warning timing, as most drivers agreed that warning timing was "just right," especially with the LDW system.

Design Issues

At this time it is unclear exactly how the actual deceleration levels shown on the previous page map to deceleration levels needed in CSW systems, however, the results should be generally applicable if the "lead vehicle deceleration level" is assumed to be comparable to deceleration level needed to drop the subject vehicle to an acceptable speed in CSW situations. Also, it is likely that the "hard normal" braking deceleration levels are more aggressive than would be needed in CSW situations because it represents "last second" braking.

Cross References

Design of ICWs for FCW Systems, 7-2; Design of ICWs for LCW Systems , 8-2;
Design of Lane Drift Warning ICWs for RDCW Systems, 9-2; Design of Curve Speed Warning ICWs for RDCW Systems, 9-6

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
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CHAPTER 3. AUDITORY WARNINGS

When to Use Auditory Warnings

Introduction

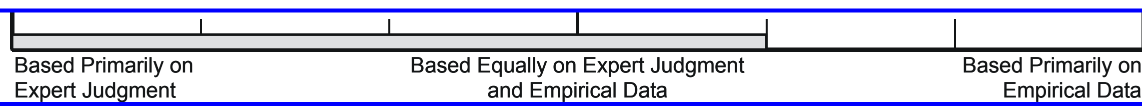
When to use auditory warnings refers to the contexts in which auditory signals should be used to provide warning information to drivers. Auditory warnings can be effective at improving driver awareness of a warning or hazard, reducing perception-reaction times, and improving overall performance. However, when auditory warnings are used inappropriately, they can be startling or annoying. The 1996 COMSIS Guidelines (Reference 1) include extensive guidance regarding the use of auditory signals in the contexts of both ICWs and CCWs. Current research generally supports the COMSIS recommendations and provides additional information that should aid in determining when it is appropriate to use auditory warnings.

Design Guidelines

Use auditory warnings in situations where it is critical to capture the driver's attention.

Appropriate situations for using auditory warnings include the following:

- To present high priority alerts and warnings (ICW).
- To provide a warning to drivers in situations in which they may be distracted or looking away from a visual display.
- To draw attention directly to the location of a potential crash threat.
- As the primary modality in an ICW, where it can be used in conjunction with visual (or haptic) displays that provide redundant cues to the driver.
- To indicate the onset of a system malfunction or limitation. Use a brief auditory tone followed by a continuous visual message.
- To augment a visual warning display in a non-time-critical situation.



Heuristics to use when selecting auditory warnings

Auditory warnings are good for:

- Getting the attention of a driver who is distracted or looking away from a visual warning.
- Time-critical information.
- Low-complexity, high-priority messages.
- Few and short messages.
- Discrete, sequential, or spatially-localized information.

Table adapted from Reference 2

Auditory warnings are *not* good for:

- Frequent warning messages because they are obtrusive and can be annoying.
- Continuous information.
- High complexity/informational messages.
- High-noise environments that can mask auditory warning signals (techniques for mitigating auditory masking may be necessary).

Discussion

Current sources concur with the 1996 COMSIS recommendation that auditory messages should be reserved for ICWs only and should be the primary warning modality. The advantage of auditory warnings is that they are omnidirectional signals that can command attention regardless of where the driver is looking. In a series of closed-track CAMP studies (Reference 3), naïve drivers that were intentionally distracted prior to a surprise braking event reported noticing the auditory component of a multi-modal warning much more often than the visual component (i.e., 99 percent versus 17-50 percent). 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.

Most of the relevant literature suggests that operator performance can be improved by combining auditory and visual messages (e.g., References 2, 3, 4, and 5). In particular, redundant visual displays that are visually conspicuous can serve as a backup method for drawing the driver's attention to a warning if the auditory signal is masked by in-vehicle noise (e.g., wind and road noises, radio sounds, conversations with passengers, etc.) or for drivers with hearing impairments (References 2 and 3).

The results from Reference 6 indicate that if there is a speaker located in the direction of a crash threat, then most drivers can localize a warning to within 10-20 degrees of the speaker, which is sufficient for providing general information about the location of the threat (e.g., forward, left-side, right-side, etc.). Similarly, auditory signals can be used to augment a visual display or to provide an indication that a visual display requires attention by using the same auditory localization approach or through the simple association of the sound and the display. This can apply to systems such as LCW systems in which warning information about potential conflicts becomes more important if the turn signal is activated, or to system malfunction indicators that may be displayed less prominently.

Design Issues

It may be advantageous to suppress the auditory warning as soon as the driver applies the brakes, because the driver is presumably aware of the potential crash situation at that time. Otherwise, if the CWS determines that the threat still exists at the time the driver releases the brakes, the ICW will again activate, which may distract the driver or be perceived as a nuisance. A period of delay following the brake release before reactivating the ICW can reduce or eliminate unwanted auditory alarms (Reference 6).

The driver should be aware of the state of the collision warning system. Reference 3 recommends that a brief auditory tone should indicate the onset of a system limitation or malfunction (i.e., the CWS ceases to provide some or all of its designed capability), and a visual display should continually indicate the limitation or malfunction.

Cross References

Determining the Appropriate Auditory Signal, 3-4
Perceived Urgency and Annoyance of Auditory Warnings, 3-12
When to use Visual Warnings, 4-1

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. International Organization for Standardization (ISO). (2005). *Road vehicles – Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems* (ISO/TR 16532). Geneva, Switzerland: International Organization of Standards.
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Determining the Appropriate Auditory Signal

Introduction

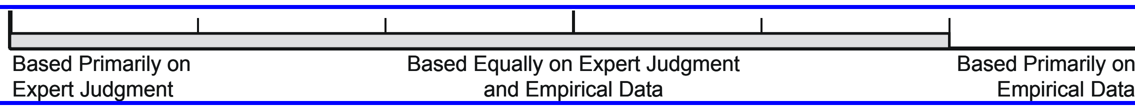
Determining the appropriate auditory signal means choosing the type of auditory signal (simple tone, earcon, auditory icon, or speech message) that will provide the most effective auditory warning under expected conditions or that will best augment other necessary visual information. The current research provides greater detail than the 1996 COMSIS Guidelines (Reference 1) regarding the appropriateness of use for different types of auditory signals. Furthermore, current sources differ somewhat from the COMSIS Guidelines regarding the use of speech displays in imminent warnings.

Warning Type	Explanation	Example
Simple Tone	Single or grouped frequencies presented simultaneously.	Square wave
Earcon	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 Icon	Familiar environmental sounds that intuitively convey information about the object or action they represent.	Car horn or skidding tire sounds
Speech Message	Voice messages that add information beyond pure sound.	“Danger”

Adapted from Reference 2

Design Guidelines

- Use simple tones and auditory icons when an immediate response is required.
- Auditory icons are recommended for collision warning applications where short reaction times are required.
- Speech-based warnings should be used sparingly, especially if false or nuisance rates are expected to be high.
- Speech messages may be used for simple informational or status messages that are not time critical.



Ratings of auditory signals for collision warning functions

Functions	Example Message	Simple Tones	Earcons	Auditory Icons	Speech Messages
Informational (e.g., system status)	• Radar dirty • Sensor malfunction • Warning disabled	Poor	Poor	Poor	Fair
Cautionary Warning	• Headway gap too small • TTC too short • Closing rate too fast	Poor	Fair*	Fair*	Poor
Imminent Warning	• Collision imminent • Immediate action required	Good	Poor	Good	Fair

Adapted from Reference 2

*Although auditory warnings are not generally recommended for CCWs because of the potential for high false-alarm rates, under appropriate conditions (with low false-alarm rates), earcons and auditory icons could potentially be useful in this application (see page 3-8).

Discussion

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 (Reference 5). However, tones can potentially be considered annoying and, therefore, might be best-suited only for conditions in which getting the drivers' attention is critical (References 1 to 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 (Reference 4).

Earcons often can be used to generate sounds that are friendlier and less obtrusive, which are useful properties for CCWs. 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 (References 2 and 4).

Auditory icons are most effective when they can be mapped to everyday, naturally occurring sounds. It has been shown that when appropriate auditory icons are used to announce a hazardous condition, the meaning can be recognizable by most drivers (Reference 6). Auditory icons in collision warning applications can reduce reaction times to collision events and produce faster reaction times than simple tones or speech (References 6 and 7). Reference 7 also found that drivers were more likely to respond to a false alarm if it was an auditory icon (15.6 percent) versus a simple tone (9.4 percent) or speech warning (8.3 percent), which arose from drivers adopting a more lenient response criteria with auditory icons.

Speech warnings may not be well suited for time-critical situations where an immediate response is required. Reference 5 found that drivers had longer reaction times when using a speech-based ICW relative to a tone-based ICW (see also References 7 and 8). In contrast, Reference 9 found that reaction times and times to reach peak deceleration were shorter when using a speech-based ICW than when using a tone-based ICW. In any case, the length of the message can increase the driver's response time (Reference 2). Moreover, because they are inherently intrusive, drivers may view speech messages as unacceptably annoying, particularly during the occurrence of false or nuisance alarms. In addition, speech warnings are perceived as quieter than non-speech warnings, all else being equal (References 2, 10, and 11). Nonetheless, 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 (Reference 2).

Design Issues

One issue to consider when using auditory icons is whether the driver may become confused when presented with an auditory icon that occurs naturally on the road, especially if it is in a different driving context. For example, an auditory icon that sounds like a horn honk could potentially be confused with a real horn outside the vehicle and consequently initiate an unwanted response (e.g., the driver could ignore the warning; Reference 7). At this point, there is insufficient research on this issue to make any conclusions about how likely this is to occur and how serious of a problem it may be. However, a prudent course of action when using auditory icons is to design the sound and its presentation so that it is perceived as emanating from inside the vehicle, and to base the selection of auditory icons on extensive empirical testing.

Cross References

When to Use Auditory Warnings, 3-2
Desired Characteristics of Auditory CCWs, 3-8

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Campbell, J.L., Richman, J.B., Carney, C., and Lee, J.D. (2002). *In-vehicle display icons and other information elements. Task F: Final in-vehicle symbol guidelines* (FHWA-RD-03-065). Washington, DC: Federal Highway Administration.
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11. Tan, A.K. and Lerner, N.D. (1995). *Multiple Attribute Evaluation of Auditory Warning Signals for In-Vehicle Crash Avoidance Warning Systems* (DOT HS 808 535). Washington, DC: National Highway Traffic Safety Administration, Office of Crash Avoidance Research.

Desired Characteristics of Auditory ICWs

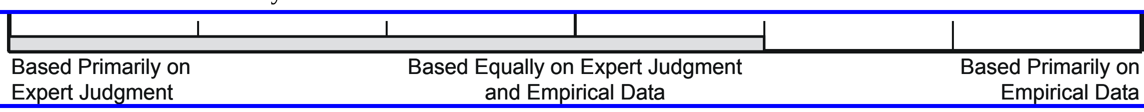
Introduction

Desired characteristics of auditory ICWs refers to the attributes of auditory warnings that most effectively draw the driver's attention to the potential crash threat or to a visual warning display when a crash is imminent. Characteristics of auditory warnings that convey different levels of urgency are discussed separately in the guideline on page 3-12.

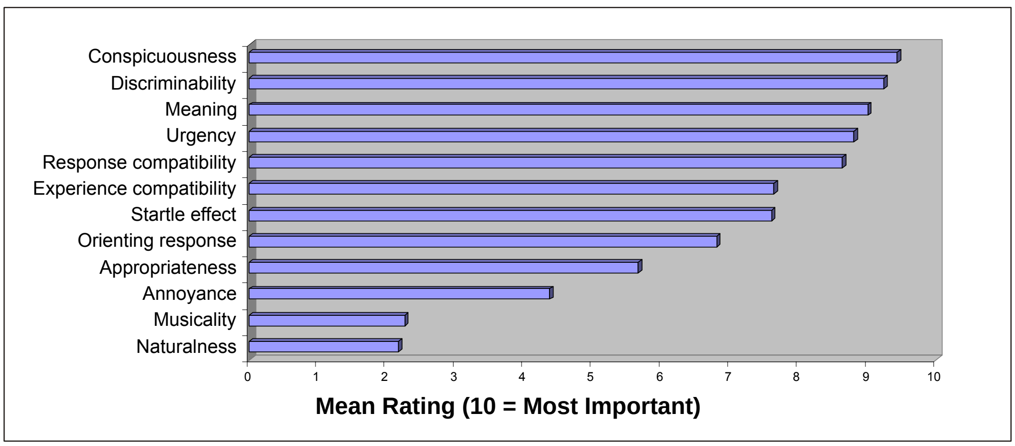
Design Guidelines

Auditory signals should be used to present ICWs and should be conspicuous, be obtrusive, convey a high level of urgency, and exhibit good attention-getting properties.

Display Type	Use simple tones or auditory icons.
Urgency	Auditory warnings should convey more urgency than other non-CWS auditory signals in the vehicle.
Discriminability	Auditory alerts should use distinctive sounds that are easily distinguished from other auditory signals. Vehicles that are equipped with more than one CWS should use auditory signals that are distinguishable between CWS alerts.
Temporal Attributes	Time-varying auditory signals, such as intermittent beeps or warbling sounds, can get attention, facilitate discrimination between signals, and provide cues about warning urgency.
Conspicuity	When possible, any in-vehicle system or device that introduces conflicting auditory signals into the vehicle should be reduced in volume—and ideally should be muted—during the presentation of an auditory warning.
Intensity (Volume)	The amplitude of auditory signals should be in the range of 10–30 dB above the masked threshold (MT); however, the signal should not exceed an absolute maximum of 90 dBA.
Spatial Localization	Do not use virtual speakers—sound images that are perceived to emanate from between two or more physical speakers—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.



Rated importance of various attributes of auditory ICWs



The figure above shows the results of a study by Reference 1. Subject matter experts (SMEs) rated how important they felt various attributes were in the design of ICWs. Note that startle effect and annoyance are undesirable (negative) attributes.

Discussion

Current sources generally agree with the 1996 COMSIS recommendations (Reference 2) that auditory warnings should be distinctive, used in high-priority situations, and reserved for use in ICWs only. They should also convey the high level of urgency associated with an imminent crash. In addition, they should capture the driver's attention to increase awareness of a potential crash threat or of necessary visual information. However, auditory warnings should not startle or annoy the driver (e.g., References 3 and 4). To improve distinctiveness and conspicuity, some sources recommend that continuous pure tones should be avoided and that tones should be intermittent with short intervals. Temporal attributes of effective tones include intermittent patterns of pulses with various fixed widths, pulses with widths that vary with time, and tones with frequencies that increase or decrease with time (e.g., warbling sounds) (References 3, 4, 5, and 6).

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. Localization acuity is generally poorer for sounds on the median plane (0- and 180-degrees azimuth). Also, sound images that are generated using virtual speakers tend to be associated with poorer localization acuity, particularly with low-bandwidth signals under high noise conditions (References 7 and 8). In systems that integrate multiple CWSs, localization may be necessary to differentiate warnings generated from each system (e.g., by using an auditory signal presented in front for LCW systems, and on the side of the hazard for LCW systems; References 4, 5, and 9).

The 1996 COMSIS Guidelines recommend that the warning intensity should be at least 20 dB and no more than 30 dB above the MT. The MT of a sound represents the intensity level at which a sound presented among masking "background" noises first becomes audible to a listener, after accounting for sound aspects such as pitch and harmonics, etc. Current sources indicate that drivers can discern auditory warnings at a level of less than 20 dB above the MT. References 3, 4, and 10 suggest that the minimum intensity of auditory ICWs should be 10–15 dB above MT in order for the warning to be detectable. However, Reference 5 agrees with the lower limit of 20 dB above MT recommended in the COMSIS Guidelines. Most sources agree that the amplitude of auditory signals for ICWs should not exceed the MT by more than 30 dB and that the maximum amplitude of the warning should be limited to 90 dB. Note that muting of any in-vehicle systems that generate competing auditory information or noise (e.g., stereo system and fan) may also be appropriate (Reference 6; see also the guideline on page 2-4).

Cross References

How to Integrate Warning Systems, 2-6
Desired Characteristics of Auditory CCWs, 3-8
Perceived Urgency and Annoyance of Auditory Warnings, 3-12

References for the Design Guideline

1. Tan, A.K. and Lerner, N.D. (1995). *Multiple Attribute Evaluation of Auditory Warning Signals for In-Vehicle Crash Avoidance Warning Systems* (DOT HS 808 535). Washington, DC: National Highway Traffic Safety Administration, Office of Crash Avoidance Research.
2. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
3. Campbell, J.L., Richman, J.B., Carney, C., and Lee, J.D. (2002). *In-vehicle display icons and other information elements. Task F: Final in-vehicle symbol guidelines* (FHWA-RD-03-065). Washington, DC: Federal Highway Administration.
4. International Organization for Standardization (ISO). (2005). *Road vehicles – Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems* (ISO/TR 16532). Geneva, Switzerland: International Organization of Standards.
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Desired Characteristics of Auditory CCWs

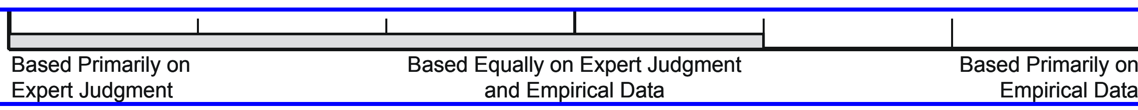
Introduction

Desired characteristics of auditory CCWs refers to the attributes of auditory warnings that provide effective cautionary warnings while minimizing the level of annoyance that can occur when repetitive auditory signals are presented. The 1996 COMSIS Guidelines (Reference 1) recommend that auditory warnings should not be used for CCWs. Current research generally agrees with the COMSIS guideline but provides additional information regarding how to implement auditory CCWs if it is determined that their use is appropriate.

Design Guidelines

Avoid using auditory signals for CCWs unless the advantages clearly outweigh the disadvantages. If auditory displays are used for CCWs, signals should be designed to reduce the level of annoyance.

Display Type	Use earcons or appropriate auditory icons to indicate the approach of a potential conflict. Avoid sounds that are overly obtrusive or startling.
Urgency	Auditory warnings should convey less urgency than the level of urgency in ICWs.
Discriminability	Auditory alerts should use distinctive sounds that are easily distinguished from other auditory signals.
Temporal Attributes	Auditory signals should either be continuous or be intermittent with long intervals.
Intensity (Volume)	The intensity of the CCW auditory signal should be less than the intensity of the ICW signal. A level of 15 dB above the MT (assuming ICW intensity of 20 dB above the MT) is recommended.
Annoyance	Avoid sounds that are annoying. Use pleasant sounds with gradual onset and offset rates. Minimize the rate of false and nuisance alarms to reduce the frequency with which CCWs occur.



Comparison of auditory signal characteristics for CCW versus ICW

CCW Characteristics	ICW Characteristics
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).

Adapted from References 5, 6 and 7
[1]See page 3-12

Discussion

Current sources generally agree with the 1996 COMSIS recommendations that auditory warnings should be avoided for CCWs. For example, Reference 2 recommends avoiding the use of auditory signals for advisory warnings because of the increased potential for the driver to be annoyed, startled, or both. In contrast, one set of guidelines allows the use of auditory CCWs, citing simulator tests that employed both imminent and cautionary voice warnings (Reference 3).

Although auditory displays generally should be avoided for CCWs, some references provide guidance concerning how to present auditory CCWs in the event that it is determined that their use is appropriate. Guidelines in Reference 5 recommend that cautionary warnings should exhibit the following characteristics: low signal (or pattern) repetition rate, low intensity, low fundamental frequency, and small frequency oscillations within auditory patterns. Reference 6 recommends that auditory CCWs should "be a continuous sound or an intermittent single sound with a long interval, should not be an annoying tone, and should have sufficient sound pressure to override background noise." Other sources recommend choosing pleasant sounds, such as one- or two-tone musical sounds or other sounds with gradual onset and offset rates (References 2, 5, and 7).

Although auditory signals for CCW should be less obtrusive and more "friendly" than those used in ICWs, CCW signals should still be distinctive and portray a level of urgency that is appropriate for the level of potential conflict they represent. References 5 and 8 recommend that the intensity of 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 guidelines 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 that convey different levels of urgency are found on page 3-12.

Design Issues

Reducing the rate of false alarms could potentially improve the acceptability of auditory CCWs. The guideline on page 2-10 provides strategies for reducing false-alarm rates.

Cross References

How to Prevent False or Nuisance Warnings, 2-10
Determining the Appropriate Auditory Signal, 3-4
Desired Characteristics of Auditory ICWs, 3-6
Perceived Urgency and Annoyance of Auditory Warnings, 3-12

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
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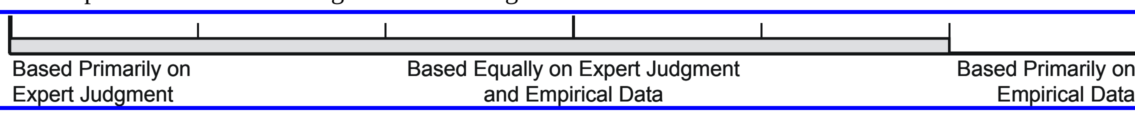
Desired Characteristics of Speech-Based Warnings

Introduction

Desired characteristics of speech-based warnings refers to defining the attributes of auditory signals that best present information through voice messages. Voice messages add information beyond pure sound and may be suitable for some warning applications. The 1996 COMSIS Guidelines (Reference 1) present an extensive series of design recommendations for auditory speech displays that cover many different aspects of how they should be presented. Recent empirical findings related to speech warnings provide additional information regarding false-alarm rates, annoyance, the use of preceding tones, and the general effectiveness of speech warnings.

Design Guidelines

- When used in conjunction with a textual visual warning, speech warnings should be redundant to the visual message.
- If speech must be used in a time-critical application, the message should be kept to a single word or a short phrase with the fewest number of syllables possible.
- Cautionary warnings should be limited to three or four information units (e.g., “Vehicle ahead—merge right”)
- Do not try to make the voice sound too human. A machine voice will help to cue its identity when it speaks.
- Synthesized speech must be clear and intelligible, particularly when pronounced at high word-rates.
- Use a word rate of 150 to 200 words per minute (wpm) to convey the urgency of the warning.
- A male or female voice may be used; however, a synthesized male voice is recommended.
- Do not precede a voice warning with an alerting tone.



Examples of speech warnings

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

Adapted from Reference 2

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 Reference 2

Discussion

The COMSIS Guidelines state that ICWs may be comprised of either speech or non-speech signals. Current sources generally indicate that speech-based warnings may not be as effective at representing a high level of urgency or producing appropriate reaction times as non-speech warnings (e.g., References 2, 3, 4, 5, and 6). However, a study of intersection CWSs by Reference 7 resulted in the opposite effect, that speech-based warnings produced shorter reaction times and times-to-peak deceleration when compared with tones. This contradictory finding may indicate that the effectiveness of speech warnings in eliciting faster responses is dependent upon the context in which speech warnings are presented (e.g. intersection approach vs. headway-keeping) (Reference 7). The following design issues provide information that should aid in maximizing the distinctiveness, conspicuity, and intelligibility of speech messages while minimizing both cognitive processing time and the potential for annoyance.

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 (References 2 and 8).

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 and differentiated from other speech and sounds. However, synthesized speech is recommended because the qualities of synthesized speech are distinctive and attention-getting. A machine-like voice also will better cue the driver to its identity. Nonetheless, caution must be exercised to ensure the intelligibility of a synthesized speech alert (References 2 and 9). The voice may be male or female; however, the female synthesized voice may require greater intensity to achieve a level of effectiveness that is comparable to the male voice. In Reference 4, female voice messages received poorer ratings for loudness and overall effectiveness than male voices. 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 (References 2 and 9).

Other characteristics of speech warnings include word rate, pitch, and vocabulary. According to Reference 9, faster, more accurate reactions can be realized using higher speech rates and shorter messages. Reference 8 recommends that the frequency range for in-vehicle auditory speech signals should be 200 Hz to 8000 Hz. In addition, when used in conjunction with a textual visual warning, speech warnings should be redundant to the visual message.

Cross References

When to Use Auditory Warnings, 3-2
Determining the Appropriate Auditory Signal, 3-4

References for the Design Guideline

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Perceived Urgency and Annoyance of Auditory Warnings

Introduction

Perceived urgency and annoyance of auditory warnings refers to the subjective impression that a signal gives to the person hearing it. The 1996 COMSIS Guidelines (Reference 1) recommend that auditory warnings should communicate a level of urgency that is consistent with the urgency of the potential crash conflict. This is called "urgency mapping." In addition, the COMSIS Guidelines provide a brief table of auditory warning characteristics that convey varying levels of perceived urgency. The current guidelines provide additional information that will aid in designing warnings that convey appropriate levels of urgency.

Design Guidelines

Auditory alerts should communicate a level of urgency that is consistent with the urgency of the hazard. Signal attributes that convey differing levels of urgency are provided in the table below.

To increase the perceived urgency:

- Use faster auditory signals.
- Use regular rhythms.
- Use a greater number of pulse burst units (4).
- Use auditory signals that speed up.
- Use high fundamental frequencies.
- Use a large pitch range.
- Use a random pitch contour.
- Use an atonal musical structure.

To decrease the perceived urgency:

- Use slower auditory signals.
- Use irregular rhythms.
- Use a fewer number of pulse burst units (1).
- Use auditory signals that slow down.
- Use low fundamental frequencies.
- Use a small pitch range.
- Use a down or up pitch contour.
- Use a resolved musical structure.

Temporal Parameters

Speed (slow = 1.5 pulse/sec; fast = 6 pulse/sec)
Rhythm (regular = all pulses equally spaced; irregular = pulses not equally spaced)
Number of units (1 = 1-4 pulse burst; 4 = 4-4 pulse bursts)
Speed change (slowing down; speeding up)

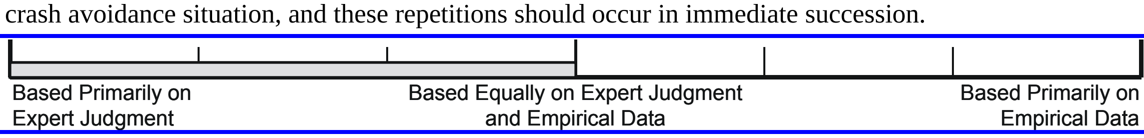
Melodic Parameters

Fundamental frequency (low = 200 Hz; high = 800 Hz)
Pitch range (small = 3 semitones; large = 9 semitones)
Pitch contour (down/up; random)
Musical structure (resolved = from natural scales; atonal = random sequence of pulses)

From Reference 2

To Minimize Annoyance:

- Sound characteristics of pulse duration, burst density, sound type, and speed all increase perceived urgency more than perceived annoyance.
- Minimize the rate of false or nuisance alarms to reduce the potential for annoyance.
- Avoid continually repeating a warning. An auditory warning should not be repeated more than three times per crash avoidance situation, and these repetitions should occur in immediate succession.



Effects of auditory signal characteristics on urgency and annoyance

Characteristic	Effect on Urgency	Effect on Annoyance
Duration of sound (Pulse)	Longer: substantially more urgent	Longer: slightly more annoying
Burst density	High: substantially more urgent	High: slightly more annoying
Speed	Faster: substantially more urgent	Faster: slightly more annoying

From Reference 2

Discussion

The results of recent research related to the perceived urgency of auditory signals have shown that varying certain acoustical parameters has a strong and consistent effect on a person's subjective impression of the urgency of the warning. The ability to provide accurate urgency mapping is extremely important because greater perceived urgency of a warning is associated with faster reaction times (Reference 2). Signal attributes that can provide urgency cues include time-varying characteristics, frequency characteristics, and signal complexity (Reference 2, 3, 4, and 5). Some guidelines suggest increasing the intensity (volume) to provide an increase in the level of perceived urgency (e.g., References 3 and 4). In addition, Reference 5 determined that for speech warnings, perceived urgency generally increased with an increase in intensity. However, Reference 6 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. When determining whether to use intensity as an urgency cue, these results should be weighed against the guidelines on pages 3-6 and 3-8 related to the effects of intensity on conspicuity and distinctiveness.

Design Issues

An important tradeoff exists between alerting and annoying when using auditory warnings. Repetitive auditory signals (i.e., those in cautionary warnings) and frequent false alarms can overwhelm the driver or become annoying or distracting. These factors may cause the driver to ignore auditory warnings altogether (References 2, 7, and 8). In a simulator study, auditory icons (e.g., car crash sound) and tones were highly rated as both conveying urgency and being annoying (Reference 9). In Reference 10, participants considered the CAMP tone to convey just the right level of urgency. However, more than half of participants also indicated that they would turn the sound off. Reference 11 concluded that the CAMP tone may not be appropriate for FCW systems that produce high numbers of false alarms because the tone could be considered by some drivers as too annoying. On the other hand, the CAMP tone may be appropriate for FCWs that produce few false alarms because its obtrusiveness and attention-getting properties outweigh the potential for annoyance. Reference 2 indicates that certain quantifiable sound parameters such as speed, number of repetitions, and frequency have a greater effect on urgency than on annoyance. The ability to quantify this subjective assessment allows designers to develop a set of auditory signals for CWSs that have higher urgency without substantially increasing annoyance.

Cross References

Desired Characteristics of Auditory ICWs, 3-6
Desired Characteristics of Auditory CCWs, 3-8
Desired Characteristics of Speech-Based Warnings, 3-10

References for the Design Guideline

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CHAPTER 4. VISUAL WARNINGS

When to Use Visual Warnings

Introduction

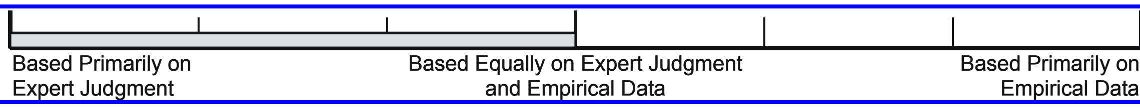
The issue of when to use visual warnings refers to the warning contexts in which it is appropriate to use visual displays to provide warning information to drivers. This issue is important because if visual warnings are used inappropriately or at the wrong time they can be distracting to drivers, or suffer the opposite problem of not being sufficiently noticeable when they must convey critical information. This topic was not specifically covered as a separate recommendation in the COMSIS Guidelines (Reference 1). However, those guidelines did present information that is relevant on this topic throughout the section on visual warnings. The current guidelines bring together the guidance from the COMSIS Guidelines with information from more recent research.

Design Guidelines

Use visual warnings to provide continuously available information in situations where it is not critical that the visual warning will be relied upon to capture the driver's attention.

Applicable situations include:

- Providing redundant or supplemental information that accompanies a primary auditory or haptic ICW.
- Providing 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 ICW for a LCW system that is presented on the rear-view and side-view mirror, or on an A-pillar).
- Providing continuous lower-priority information such as a CCW.



Heuristics to use when selecting visual warnings

Visual warnings are good for:

- Unobtrusive warnings / non-urgent information / self-paced presentation.
- Complex, long, and many messages.
- Discrete and continuous information.
- Spatial information.
- Temporally and spatially free access.

Visual warnings are *not* good for:

- Conveying time-critical information / forced-paced presentation.
- Poor illumination conditions.
- Configuration with unrestricted driver viewing angle and position.

Table adapted from Reference 2

Discussion

Visual warnings are not recommended as the primary source of warning information in time-critical situations because there is a good possibility that drivers will not receive the information in a timely manner. A strong and likely sufficient basis for providing the guideline above is the theoretical constraints on driver capabilities identified from basic human performance. In particular, one prerequisite for an effective visual warning is that it appear in the user's expected field of view (in other words, a visual warning is not omnidirectional). Thus, a visual warning presented on the left side of the instrument panel likely will not be seen in a timely manner if the driver is looking down at the radio or performing a shoulder check. Adding to this limitation is the possibility that drivers can still miss a visual warning even if they are looking in its general direction if they are actively focusing their attention elsewhere in the visual scene. For example, a driver reading a street sign can miss a visual warning in plain sight if his or her attention is closely focused on the sign. Thus, a central limitation of visual warnings is that they cannot be relied upon to convey the intended information precisely when needed. Note that the consensus among most related guidelines documents is that visual warnings not be used as the exclusive warning source for just these reasons (e.g., References 3, 4, and 5).

The specific data regarding this issue are more limited. The most helpful information on this issue comes from Reference 4, which involved deliberately distracted drivers in a closed-track environment. In this study, drivers that were largely unaware of an onboard CWS noticed an auditory alarm 99 percent of the time, while a corresponding visual warning was only noticed 17-50 percent of the time. On the other hand, two other studies that compared braking performance between visual-warning only and combined auditory-visual warnings (among other combinations) found no advantage of auditory-visual warnings over just visual warnings alone (References 5 and 7). However, these studies may have represented optimal conditions for the visual-only conditions, in which drivers were more aware of the visual information than normally would be the case. More specifically, in one study, the visual warning was part of a head-up display (HUD) that was almost always within the field of view (Reference 5), and the other study used a headway display to which drivers may have paid an atypically high amount of attention to because it was novel and provided continuous information (Reference 7).

Design Issues

In some situations, it may be sufficient to provide only visual warning information, which is beneficial if a high number of false alarms are expected. The circumstance under which this would be appropriate would be one in which drivers could be expected to consistently attend directly to or near the warning information as a part of their normal driving activities. An example of this is the LCW system used in Reference 8. This system was designed for "parallel usage" in which the primary objective of the system is to provide information that augments driver decision making and in which drivers clearly understand that they are responsible for actively acquiring that information from the warning system. In the field test for this system, 88 percent of test drivers reported that the LCW system provided adequate warning of potential hazards. Note, however, that modification of driver behavior is likely to be necessary for this type of system to work effectively, because under normal conditions drivers only look at the rear-view or relevant side-view mirror approximately 50 percent of the time (compared to 99% for glances towards the forward center), which means that they could otherwise miss critical visual-only warning information presented at the mirror locations (Reference 9).

Cross References

Design of ICWs for FCW Systems, 7-2
Design of ICWs for LCW Systems, 8-2

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. International Organization for Standardization (ISO). (2005). *Road vehicles – Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems* (ISO/TR 16532). Geneva, Switzerland: International Organization of Standards.
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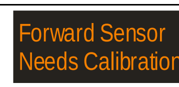
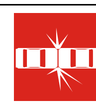
Determining the Appropriate Type of Visual Display

Introduction

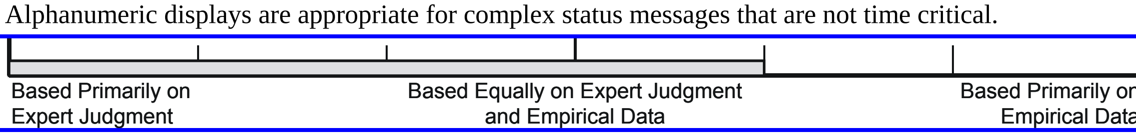
Determining the appropriate type of visual display refers to the selection of a visual warning display format that most appropriately compliments the information type, functional requirements, and timing parameters of the intended message. The different types of displays are shown in the table below. This topic was not specifically covered as a separate recommendation in the 1996 COMSIS Guidelines (Reference 1) and the current guidelines bring together the recommendations from more recent research and analysis.

Display Type	Explanation	Example	
Analog Display	Provides a graphical representation of continuous information.		Scale-based FCW
Discrete Display	Provides binary on/off information.		"Vehicle detected" status indicator
Digital Display	Information is presented directly as a number.		Headway distance display (in meters)
Alphanumeric Display	Information is presented as messages in full or abbreviated form.		Complex system error message
Symbol/Icon	Simple graphic signs that transmit message information. Note that some simple and familiar alphanumeric displays (e.g., Stop!; Brake!) may function as symbols.		FCW Icon

Adapted from Reference 2.

Design Guidelines

- The abrupt onset of a conspicuous symbol/icon or discrete display (whose significance is clearly recognizable) is the most appropriate method for providing time-critical ICW information visually. In such situations, the visual display should be accompanied by an auditory warning.
- Analog, discrete, and symbol displays may be appropriate for providing CCW information provided that they are clearly distinguishable from ICW displays and do not add distracting visual clutter to the overall display.
- Icons and discrete displays are appropriate for simple/binary status indication provided that they are clearly distinguishable from alerting displays and do not add distracting visual clutter to the overall display.
- Alphanumeric displays are appropriate for complex status messages that are not time critical.



Ratings of the efficacy of various visual display types.

Display Type	ICW	CCW	Status	Comment
Analog Display	Poor	Fair-Good	Fair	—
Discrete Display	Unknown	Fair-Good*	Good	*Effectiveness depends on presentation context conveying correct meaning.
Digital Display	Poor	Poor*	Poor	*Lacks clear cues that warning or alert stages reached.
Alphanumeric	Poor	Poor	Poor-Good*	*Only appropriate for non-time-critical complex information.
Symbol/Icon	Good	Fair-Good*	Fair-Good*	*CCW and status icons must be clearly distinguishable from ICW icons.

Discussion

Purely analog displays provide poor ICW information because the critical alert level display only differs from the cautionary level in terms of degree, and it likely does not present the critical alert with sufficient conspicuity (Reference 3). However, analog-based scale displays may be effective for providing less-critical CCW information. In particular, mean headway was significantly lengthened under regular driving and light lead-vehicle braking conditions in one on-road study (Reference 4). On the other hand, another driving simulator study found that this type of display provided no significant benefit (Reference 3). Combining an analog-based scale display with other looming-vehicle information, and an abrupt ICW onset warning does appear to increase the effectiveness of analog-based displays (Reference 3).

Symbol and icon displays appear to be effective as both ICW and CCW displays, provided that the alerting display is sufficiently conspicuous. For example, in one study, a low-conspicuity ICW that was identical to the CCW (except that it flashed at 4 Hz), was less effective than the same stimulus presented as a single-stage ICW-only alert. In contrast, ICW and CCW icon displays were effectively used in another system that clearly differentiated the icon displays in terms of color, size, and form (Reference 3).

Discrete displays (e.g. simple Light Emitting Diodes [LEDs]) that lack symbolic content also can be used effectively as CCWs. While no performance data are readily available on the effectiveness of these displays, they have been implemented in CCW-like LCW displays for heavy vehicles (Reference 5). Note, however, that there is currently insufficient data available to evaluate the effectiveness of discrete displays for ICWs.

Alphanumeric displays are recommended only for status messages that cannot be easily represented with icon displays. Caution also should be taken to ensure that these displays are not presented in a way that could interfere with the driving task. This means that messages should be presented in non-time-critical situations, preferably while the vehicle is stopped.

Design Issues

It is important to consider the purpose of presenting the information when determining the most appropriate warning display. In particular, if the objective is behavioral modification (e.g., getting drivers to adopt longer headways), then drivers would likely benefit most from continuous feedback, such as that provided by an analog headway display. On the other hand, if the purpose of the warning system is solely to provide a time-critical indication of an imminent hazard, then greater emphasis should be placed on a display that is effective in capturing the driver’s attention and is easy to understand. In this case, the best display would involve a conspicuous icon/symbol or discrete display that appears abruptly within the field of regard that is relevant to the driving task at hand (e.g., near the forward field of view for lead-vehicle hazards). Whether or not an icon/symbol or a discrete display would be most appropriate in this situation would depend on whether information must be conveyed about the meaning of the message (icon/symbol is better in this case) or if it is obvious from the context what the meaning is (a discrete display may be acceptable in this case).

Cross References

Determining the Appropriate Auditory Signal, 3-4
When to Use Visual Warnings, 4-2
Determining the Appropriate Display Type for Haptic ICWs, 5-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
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Desired Characteristics of Visual ICWs

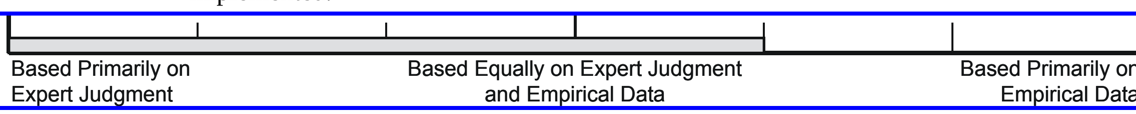
Introduction

The desired characteristics of visual ICWs refers to the key visual display properties of these warnings, such as how they are presented, their form, and their color. These characteristics influence both the information that the warnings transmit and how visible they are to the driver. The 1996 COMSIS Guidelines (Reference 1) provided recommendations that were specific to ICWs covering: attention-getting characteristics, display color, flashing rate, and discriminability aspects of ICWs. The current guideline covers the same topics and adds insights gained from more recent research.

Design Guidelines

Visual ICWs should provide information about the nature of the warning (that complements auditory or haptic ICW signals if used) and be visually conspicuous with good attention-getting properties.

Display Type	If the visual warning provides supplementary, function-related information, it should contain iconic/symbolic elements that can be quickly understood by the driver.
Onset and Flashing Rate	The attention-capturing properties of the visual warning should be maximized by having it appear abruptly within the relevant field-of-view and possibly by making it flash at a rate of 4 Hz.
Color	Using red as the primary color in the warning is most consistent with drivers' stereotypes of critical warning levels (e.g., danger). However, other considerations about warning conspicuity may necessitate using a different color (see Design Issues on the next page).
Discriminability	The ICW should be visually distinguishable and more salient than the CCW, if a CCW is also implemented.



Example icons and the intensity profile for the recommended 4 Hz ICW flicker.

CAMP One-Stage ICW

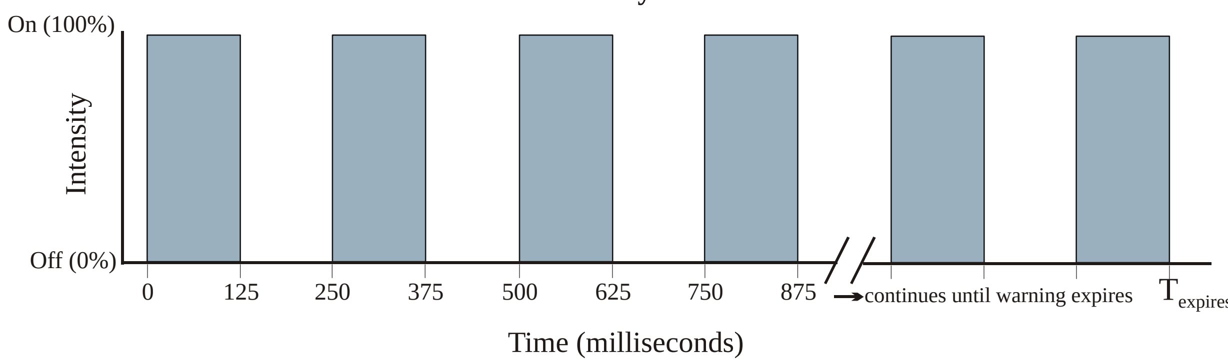
This ICW is amber instead of red to address the potential confusion with other nearby dashboard telltales.

GM Two-Stage Warning

CCW **ICW**

The ICW for this two-stage warning differs from the CCW in terms of color, form, and size.

4 Hz Flicker Intensity Profile Over Time



Adapted from References 1, 4, 5, and 7

Discussion

ICWs, if used in conjunction with concurrent auditory or haptic ICW signals, should provide redundant and complementary information about the nature of the warning either directly through its associated icon/symbol or indirectly through the context (e.g., indicator on side-view mirror if intent to change lanes is detected). This is particularly important if the auditory signal is non-specific/non-descriptive (e.g., the CAMP warning sound), if there are multiple warning systems that may not be intuitively distinguishable, or if ICWs are infrequently encountered. In these cases, the visual warning can provide specific information about the nature of the hazards (Reference 2). Existing icon design guidelines provide a good reference for developing and testing icons that are intuitive, meaningful, and visually simple (Reference 3).

Using a visual display to provide redundant information about the temporal onset of the ICW (by making it attention-getting) is also beneficial because it may improve communication of the overall alert condition if there is high ambient noise (e.g., an external music source) or if the driver is hearing impaired (Reference 4). An abrupt onset (rapid luminance change) is optimal for capturing attention, and this effect can be enhanced by flashing the visual warning at a frequency of 3 to 10 Hz, with 4 Hz being optimal (Reference 5).

Drivers typically have inherent color stereotypes for different levels of warning urgency (Reference 6). The color red is usually associated with critical, high-priority information (e.g., danger), and it is appropriate for use as part of a visual ICW (however, see Design Issues).

The ICW should be visually distinct from the CCW or any other nearby visual indicators with which it potentially could be confused. In one study, an ICW that was identical to the CCW (except that it flashed at 4 Hz while the CCW was static), was significantly less effective in alerting drivers to lead vehicle braking than just a single-stage ICW-only display (Reference 4). What qualifies as sufficiently different has not yet been fully determined. However, one study found that two-stage (ICW and CCW) visual warnings that differed in color, size, and form provided an effective level of warning as part of a HUD display configuration (Reference 7). Based on expert judgment, using an ICW that is more visually conspicuous than the CCW or other indicators (e.g., larger size, flashing presentation, spatially separate, different color), should maximize the likelihood that it will be clearly distinguishable.

Design Issues

Considerations about warning conspicuity may override standard color choice. Red is best for communicating danger, however, red icons are also used in instrument panel indicators (e.g., emergency brake and seat belt icons) that drivers see frequently. If the visual warning is displayed in close proximity and is similar enough in size and shape that it can be confused with these non-warning icons, then an alternative color (e.g., yellow/amber) may be more appropriate (Reference 4).

Cross References

How to Select the Number of Warning Stages, 2-2
When to Use Visual Warnings, 4-2
Determining the Appropriate Type of Visual Display, 4-4

References for the Design Guideline

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7. General Motors Corporation and Delphi-Delco Electronic Systems. (2002). *Automotive collision avoidance system field operation test, warning cue implementation summary report* (DOT HS 809 462). Washington, DC: National Highway Traffic Safety Administration.

Desired Characteristics of Visual CCWs

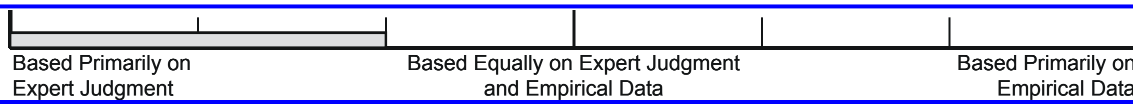
Introduction

The desired characteristics of visual CCWs refers to the key visual display properties of these warnings, such as how they are presented, their visual form, and their color. These characteristics influence both the information that the warnings transmit and how visible they are to the driver. The 1996 COMSIS Guidelines (Reference 1) provided recommendations that were specific to CCWs covering: attention-getting characteristics, display color, flashing rate, and discriminability aspects of CCWs. The current guideline expands on the same topics by adding insights gained from more recent research.

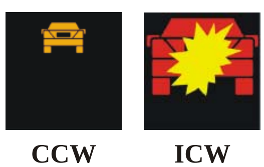
Design Guidelines

Visual CCWs should be visible and noticeable to the driver but they should be presented in a less obtrusive manner than ICWs.

Display Onset	The CCW should appear abruptly (include a luminance change component) so that it is noticeable to the driver.
Flashing	The CCW should be presented as a steady indicator (not flashing).
Color	Using yellow/amber as the primary color in the warning is most consistent with driver stereotypes for cautionary warning level. However, other considerations about warning conspicuity may necessitate using a different color (see Design Issues on next page).
Discriminability	The CCW should be visually distinct from the ICW.

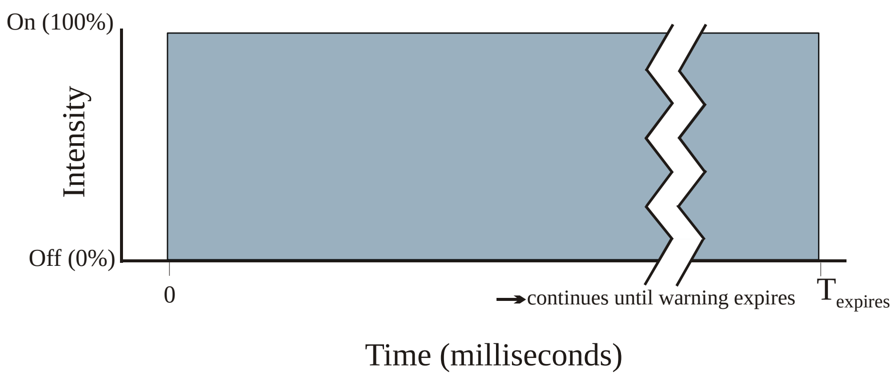


Candidate Two-Stage Warning



The CCW for this two-stage warning has a different form and "less urgent" color than the ICW in addition to being smaller in size.

Constant Intensity Profile Over Time



Discussion

There has been little research into the specific properties that CCWs should have in order to be effective. Some research has been conducted regarding CCWs as part of broader quasi-analog scale and looming displays for FCW systems, and the design implications of this research are discussed in the guideline on page 7-2.

In general, CCWs need to be noticeable to be effective. Because CCWs are likely to occur relatively often, they should not be overly obtrusive so as to avoid annoying drivers. CCWs should contain an abrupt luminance change component to make them noticeable and to facilitate attention capture. However, flashing of the warning is not recommended for two reasons. First, warning flashing should be reserved for ICWs, and second, because CCWs are likely to occur more frequently, using a flashing presentation is likely to lead to higher levels of driver annoyance (Reference 2).

As covered on page 4-6, CCWs and ICWs should be visible and noticeable to the driver. To the extent possible, dimensions of characteristics that make warnings less salient, (e.g., smaller size, no-flashing, lower-perceived-priority colors) should be assigned to the CCW rather than the ICW. Separating CCWs and ICWs spatially may also help distinguish these warnings, although there are no data available to confirm or disconfirm this claim in a driving context. Note that if the warnings are spatially separated, they should still be located close enough or visually grouped to be perceived as part of the same overall warning system. With regard to the temporal relationship between CCWs and ICWs, there are no data about whether or not CCWs should be extinguished when ICWs are presented. While extinguishing the CCW would reduce competing visual clutter, there is the potential for perceptual masking if strong apparent motion results from this configuration.

The color yellow is typically associated with “caution” type messages. Note that there is some debate regarding whether the color orange represents “danger” or something less critical, such as “warning” or “caution” (Reference 3). During development of the air bag warning label, NHTSA focus groups (See Reference 4) 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 (Reference 2).

Design Issues

In some warning display configurations, red may not be the most appropriate color to use for ICWs, because it may lead to confusion with other nearby indicators that also use the color red (e.g., emergency brake and seat-belt indicators; Reference 5). In this case, it may be necessary to use ICW colors (e.g., orange or amber) that contain a yellow color component. This could potentially lead to confusion between the ICW and a yellow CCW, and possibly to inappropriate responses (e.g., drivers braking hard because they think the CCW is actually an ICW). Although how to address this issue is unresolved, potential approaches to this problem include changing the color set, making ICWs and CCWs more discriminable in terms of their other visual characteristics, or eliminating the CCW altogether.

Cross References

When to Use Visual Warnings, 4-2
Desired Characteristics of Visual ICWs, 4-6
Design of CCWs for FCW Systems, 7-2

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. International Organization for Standardization (ISO). (2005). *Road vehicles – Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems* (ISO/TR 16532). Geneva, Switzerland: International Organization of Standards.
3. Leonard, S.D. (1999). Does color of warning affect risk perception? *International Journal of Industrial Ergonomics, 23*, 499-504.
4. Federal Motor Vehicle Safety Standards: Occupant Crash Protection [Docket No. 74-14; Notice 103], RIN 2127-AG14 (to be codified at 49 C.F.R. pt. 571. 208). Retrieved September 29, 2006 from http://www.nhtsa.dot.gov/cars/rules/rulings/Labels5.mlv.html
5. Kiefer, R., LeBlanc, D., Palmer, M. Salinger, J., Deering, R. and Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (Final Report DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.

General Characteristics of Visual ICWs and CCWs

Introduction

This guideline provides information on general characteristics that apply to both ICWs and CCWs. These include visual display properties such as display location, size, luminance, and contrast. The 1996 COMSIS Guidelines provided basic information on each of these characteristics, and have been updated with information from more recent research. Each of the visual display characteristics covered is defined below:

Location: Refers to where in the vehicle that the visual display is presented.

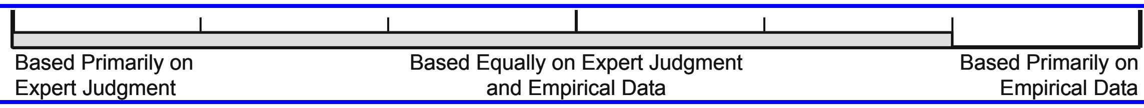
Icon Size: Refers to the spatial dimensions of the text and symbol elements within a visual display icon.

Luminance: Refers to the amount of light emitted from a surface representing the visual display.

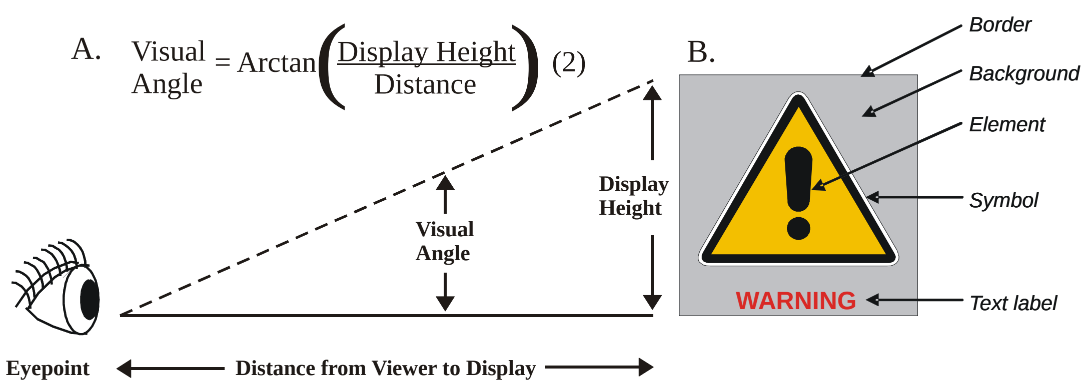
Contrast: Refers to the relationship between the luminance of a symbol and the luminance of the symbol's background.

Design Guidelines

Location	The visual display should be located within 15 degrees of the driver's expected line of sight so that it does not direct the driver's gaze away from important visual information.
Icon Size	The optimal visual angle of primary *symbol* elements of an icon is 1.43 degrees, with the minimum visual angle being 0.69 degrees. The optimal height of icon *Text* is 0.40 degrees, with the minimum height being 0.27 degrees.
Luminance	The visual display should be twice as bright as the immediate background.
Contrast Ratio	The preferred contrast ratio between the defining icon element and its background is 7:1 and the minimum recommended contrast ratio is 3:1.



Defining symbol within an icon and visual angle calculations



Part A describes the components of visual angle and its calculation. Part B shows the different elements of icons.

Adapted from Reference 2

Discussion

In general, locating the visual warning near the line of sight will increase the likelihood that it will be seen, in addition to reducing the time needed to glance at that information (Reference 3). The specific design value of 15 degrees within the line of sight is taken from Reference 1. This source also recommends that the visual display be located such that it draws the driver's gaze towards the hazard. 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. More specific recommendations for each type of CWS are presented in the relevant guidelines (see Chapters 7, 8, and 9).

The design values for icon size come from comprehensive icon guidelines developed in Reference 2. Federal Motor Vehicle Safety Standards (FMVSS) requirements for dashboard telltales call for text height of 0.26 degrees, which is slightly less than the minimum recommended text height in the current guideline. Note that Reference 4 effectively used a visual warning icon with smaller symbol (0.3 by 0.9 degrees) and text (0.2 degree height) dimensions in a FCW system. The design values from Reference 2 were selected for the present guideline because they are more conservative and because this reference source provided the most comprehensive rationale for the specific design values.

The required luminance for a visual display varies depending on the time of day. During daytime driving, high-ambient illumination can make the visual display more difficult to see. An ambient background luminance of 2,500 foot-lamberts is considered to be a representative "worst-case" scenario for daytime driving (Reference 2). On the other hand, during nighttime driving, if a display is too bright it can become a discomfort or disability glare source to drivers, especially older drivers (Reference 4). Reference 4 recommends that a sensor mechanism be implemented that uses different luminance levels for day and night driving conditions. Similarly, a mechanism to allow drivers to adjust the display luminance is also recommended, as long as drivers are not permitted to adjust the display to levels that are not visible (Reference 4). This recommendation applies to the overall luminance of icons and to the luminance of indicator lights.

Contrast greatly affects the legibility of a visual display. The design values for contrast ratio come from comprehensive icon guidelines developed in Reference 2. Other reference sources recommend that lower minimum contrast ratios are acceptable. In particular, Reference 4 recommends a minimum contrast of 2:1 and Reference 5 recommends a minimum contrast of 1.4:1 under daytime conditions and 2:1 under nighttime conditions. The design values from Reference 2 were selected for the present guideline because they are more conservative and because this reference source provided the most comprehensive rationale for the specific design values.

Design Issues

Older drivers generally have poorer visual acuity and are less sensitive to luminance contrasts than younger drivers. Thus, the design guidelines specified above accommodate older driver visual limitations. All other factors being equal, design values for size, luminance, and contrast that meet the legibility needs of older drivers will always meet the legibility needs of younger drivers.

Cross References

Desired Characteristics of Visual ICWs, 4-6
Desired Characteristics of Visual CCWs, 4-8

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Campbell, J.L., Richman, J.B., Carney, C., and Lee, J.D. (2002). *In-vehicle display icons and other information elements. Task F: Final in-vehicle symbol guidelines* (FHWA-RD-03-065). Washington, DC: Federal Highway Administration.
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CHAPTER 5. HAPTIC WARNINGS

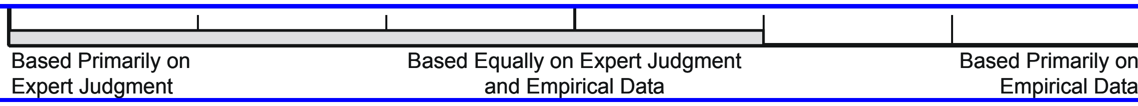
When to Use Haptic Warnings

Introduction

A key issue in the consideration and design of haptic warnings is understanding when it is appropriate to use haptic displays to provide warning information to drivers. Key examples of haptic warnings used in CWS devices include: brake pulse, accelerator counterforce, accelerator vibration, steering wheel torque, steering wheel vibration, and seat shakers. This topic was not specifically covered as a separate recommendation in the 1996 COMSIS Guidelines (Reference 1). The current guidelines bring together the guidance from the 1996 COMSIS Guidelines with information from more recent research.

Design Guidelines

- Haptic displays should be considered if an auditory ICW 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).
- Haptic warnings will be sufficiently effective only if 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).



Heuristics to use when selecting haptic warnings.

Haptic warnings are good for:

- Obtrusive, omnidirectional attention-getting, if used appropriately.
- Providing warning information if other modalities are overloaded.
- Providing simple information if it is given in the appropriate context and if it provides direct intervention in the manual control process (e.g., steering torque naturally advises a driver against further steering against the force).

Haptic warnings are *not* good for:

- Providing complex or potentially ambiguous information.
- Systems that provide limited exposure to warnings because drivers are likely to require some learning to distinguish them from natural driving sensations (e.g. rumble strips).

Table adapted from References 2 and 3

Discussion

The primary functional advantage of haptic warnings is that they have omnidirectional warning properties if properly implemented. More precisely, the appropriate haptic warning can be effective in communicating time-critical information to a driver who may not be paying attention to the driving task or who, for some reason, cannot be expected to hear an auditory warning. This feature makes haptic warnings appropriate for ICWs. Some guidelines recommend that haptic warnings can be appropriate for both ICWs and CCWs (References 3 and 4); however, these and other sources recommend not using haptic warnings for CCWs with high false-alarm rates because haptic warnings can be annoying to drivers under these conditions. Moreover, SAE Guidelines require that the use of haptic displays in aviation environments be minimized (Reference 5). Most of the empirical studies reviewed used haptic warnings for ICWs only (References 6, 7, 8, and 9). Seat vibration CCWs were used in Reference 10 and drivers reported that they were easy to understand and not annoying.

In comparison to other warning modalities, haptic warnings were found to be less effective than other types of warnings in some studies (References 6 and 7); although other studies showed that haptic warnings can still provide an overall response benefit, especially with distracted drivers (References 8 and 9). Also, some research indicates that less effective haptic warnings may work better when combined with concurrent auditory warnings (Reference 6). However, other research suggests that this strategy may lead to information overload in some situations (Reference 9).

It should be noted that although some haptic warnings seem to be less effective than auditory warnings (e.g., Reference 6), these findings may be based on research that used a haptic warning with sub-optimal characteristics. In particular, Reference 11, which involved an ICAS, evaluated a range of haptic warnings, including the 0.6 second mono-pulse used in Reference 6. The results indicate that the mono-pulse signal was much less effective than other types of haptic warnings. For now, there is insufficient data to make the claim that haptic ICWs are equally effective as auditory ICWs. It is possible that further research involving haptic warning signals with more optimal characteristics could change this conclusion.

Design Issues

Data about the interactions between haptic warnings and driver responses are limited. Specifically, some research sources raise important safety issues regarding haptic warnings that remain unanswered, such as the potential loss of vehicle control on slippery surfaces, onset delays, consequences of moving the driver's foot from its "normal" position in the vehicle, inhibiting of more appropriate driver responses, driver annoyance, and drivers mistakenly assuming that brake pulse warnings will automatically mitigate an unsafe situation (References 6 and 9).

If there is concern that drivers will misperceive or inaccurately comprehend a haptic warning, then adding a concurrent visual or auditory display is recommended. However, it is important to keep in mind that the effectiveness of combined haptic and auditory or visual warnings is not fully understood at this point, and additional testing should be undertaken to ensure that the resulting warning combination provides sufficient response benefits and does not lead to driver information overload.

Cross References

Determining the Appropriate Display Type for Haptic ICWs, 5-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Tijerina, L., Johnston, S., Parmer, E., Pham, H. A., and Winterbottom, M.D. (2000). *Preliminary studies in haptic displays for rear-end collision avoidance system and adaptive cruise control system applications* (DOT HS 808(TBD)). Washington, DC: National Highway Traffic Safety Administration.
3. Campbell, J.L., Bittner, A.C., Jr., Lloyd, M., Mitchell, E., and Everson, J.H. (1997). *Driver-vehicle interface (DVI) design guidelines for the intersection collision avoidance (ICA) system* (Final Report). Seattle, WA: Battelle Human Factors Transportation Center.
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8. Manser, M. P., Ward, N.J., Kuge, N., and Boer, E. R. (2004). Influence of a driver support system on situation awareness and information processing in response to lead vehicle braking. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 2359-2363.
9. Tijerina, L. Jackson, J., Pomerleau, D., Romano, R., and Petersen, A. (1996). Driving simulator tests of lane departure collision avoidance systems. *Proceedings of ITS America Sixth Annual Meeting, Houston, TX*.
10. LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, J., et al. (2006). Road Departure Crash Warning Field Operational Test. Washington, DC: National Highway Traffic Safety Administration.
11. Lee, S.E., Perez, M.A., Doerzaph, Z.R., Brown, S.B., Stone, S.R., Neale, V.L., et al. (2005). *Intersection collision avoidance – violation project: Final project report* (Draft Final Task 5 Report DTNH22-00-C-07007). Washington, DC: National Highway Traffic Safety Administration.

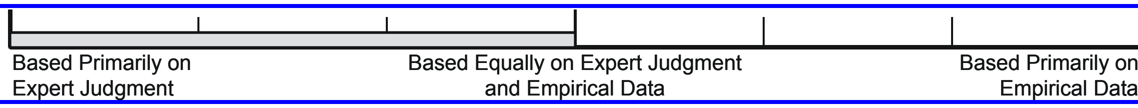
Determining the Appropriate Display Type for Haptic ICWs

Introduction

Determining the appropriate haptic warning type refers to the selection of the haptic display format that most appropriately compliments the information type, functional requirements, and timing parameters of the intended message. The haptic displays that are most relevant to CWSs are described in the table below. Recommendations from the 1996 COMSIS Guidelines are still relevant and form the basis for the current guideline (Reference 1). However, these have been updated with additional discussion and supporting information from more recent studies.

Design Guidelines

- The type of haptic display used should be intuitively associated with the situation it represents and, if possible, it also should be compatible with the driver response appropriate for the driving situation and hazard (e.g., steering wheel torque applied in the direction that moves the vehicle away from a hazard in a LCW system).
- The haptic display should also present information in a form that the driver is physically able to perceive (e.g., accelerator pedal displays are riskier because drivers may not be in contact with the accelerator—i.e. if the cruise control is engaged).



Ratings of the efficacy of various visual display types

Haptic Warning Type	Explanation	FCW	LCW	RDCW	Comment
Brake Pulse	One or more short, sudden jerks of deceleration. The driver does not need to have a foot on the accelerator or brake.	Fair	Poor	Poor	—
Accelerator Counter-force	Active accelerator pedal that provides counterforce proportional to defined error (e.g., speed, TTC, etc.).	Poor-Fair*	Poor	Poor-Fair*	*Driver's foot may not always be on accelerator.
Accelerator Vibration	Active accelerator pedal that provides vibration for general alerting.	Poor-Fair*	Poor	Poor-Fair*	*Driver's foot may not always be on accelerator.
Steering Wheel Torque	Directional torque of specified magnitude and duration applied to the steering wheel.	Poor*	Fair-Good	Fair-Good	*This will not work and may be unsafe if the steering wheel is in the center position.
Steering Wheel Vibration	Non-directional vibration of specified duration amplitude, frequency, waveform applied to the steering wheel.	Poor	Poor *	Poor-Fair	*Response compatibility is lower because steering direction is not provided.
Seat shaker	Non-directional vibration of specified duration amplitude, frequency, waveform applied to the seat or portion of the seat.	Fair-Good	Fair-Good	Good	Driver legs, buttocks, or back must be in contact with and sensitive to the shaking portion of the seat to be noticed.

Note: A rating of "Poor" was assigned to be the default if a haptic warning display is not intuitively associated with the driving situation or the appropriate driver response.

Discussion

Based on the limited data available, accelerator counterforce seems to yield improved crash-avoidance in FCWs as well as leading to drivers releasing the accelerator faster in braking maneuvers (Reference 3 and 4). Accelerator-based warnings are not recommended as the first choice for this application because it requires that the driver's foot be located on the accelerator pedal in order to receive the warning information. A brake pulse warning does not have this problem because drivers feel the corresponding deceleration sensation under all conditions. However, this type of ICW appears to be significantly less effective than auditory ICWs (Reference 5). Other types of haptic warnings that have been examined for FCW systems include steering wheel vibrations (References 6 and 7) and seat vibrations (Reference 8), but neither of these appear to be effective in reliably alerting drivers and prompting appropriate responses.

Haptic ICWs in the form of directional steering wheel torque appear to be viable warnings for LCW systems. It should be noted that the findings for passenger vehicles are based on limited research data conducted with older technologies. Nevertheless, this research suggests that discrete torque can be effective in prompting drivers to cancel unsafe lane changes and in reducing the maximum lateral deviation towards the destination lane prior to canceling that lane change (Reference 3 and 9). Also, other research suggest that the effectiveness of torque-based warnings does not disrupt normal driver steering control movements (Reference 9). Research with transit buses also finds that lane departure warnings systems based on steering-wheel torque feedback also reduce speed variability and improve lane-keeping performance and lane departure recovery on narrow "express bus lanes" under heavy traffic conditions (Reference 10).

With regards to Road Departure Crash Warning (RDCW) systems, steering wheel torque was effective with late (ICW-like) warnings, while steering vibration was not effective under these same conditions (Reference 7). On the other hand, steering vibration was better with earlier warnings and smaller heading perturbations (which are more like CCW than ICW conditions). Also of note, combining steering torque with a corresponding auditory warning may have overloaded drivers and diminished the effectiveness of the warning.

Seat shakers have been used in RDCW systems (Reference 11) and have a logical application there because they can mimic the haptic cues that drivers receive from existing infrastructure-based lane-departure notifications/warnings (e.g., raised lane markers and rumble strips). The results from Reference 11 indicate that lateralized seat pan vibrations in a LDW system were easily identified and understood by drivers, as were vibrations presented at the front of the seat in a CSW system. Note that lateralized and forward haptic warning displays could also be applicable to LCW and FCW systems that address hazards from similar locations.

Design Issues

One potential problem with haptic warnings is that drivers must make sufficient contact with the haptic display source to be able to perceive the warning. As mentioned above, this is a potential problem for accelerator counterforces because the driver's foot may be off the accelerator when the warning is presented. While there are currently no data regarding how frequently this occurs, examples are easy to imagine, such as when cruise control is engaged. Also, the increasing availability of Adaptive Cruise Control (ACC) will likely increase this problem in the future. Similarly, with seat shakers, the driver must be sensitive to the vibration stimulus. This requires that driver make contact with the shaking seat component and that the vibrations are strong enough to be noticed through heavy clothing and by older drivers who are generally less sensitive to vibrations.

Cross References

How to Make Warnings Compatible with Driver Responses, 2-8

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
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Desired Characteristics of Haptic ICWs

Introduction

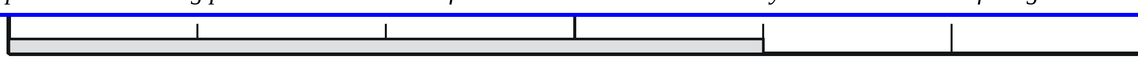
The desired characteristics of haptic ICWs refers to the attributes of haptic warnings that are associated with the best performance in terms of warning detection and prompting the appropriate driver response for the different types of warning systems. The 1996 COMSIS Guidelines provide brief, limited recommendations for vibrotactile displays, but these were not based on driving-related data (Reference 1). The current guidelines update this information with data from more recent CWS data sources.

Design Guidelines

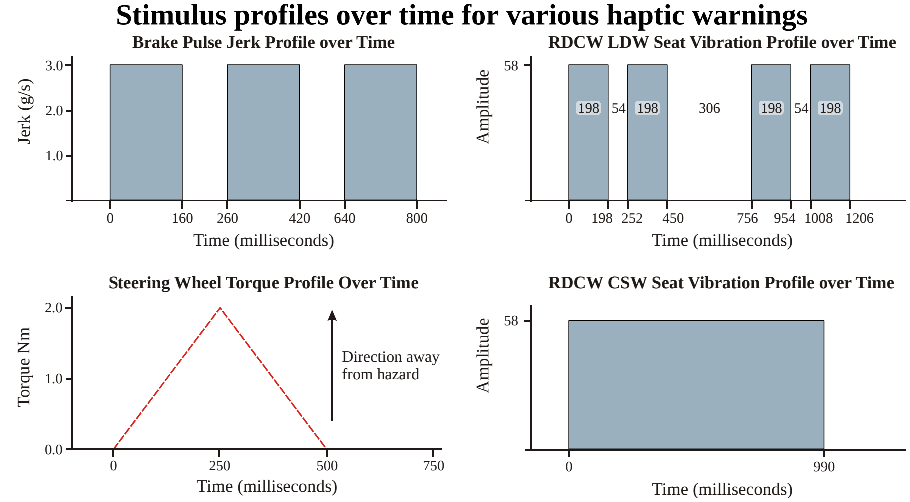
Haptic warnings with characteristics listed below are associated with the best performance for each indicated CWS.

Display	System	Guideline
Brake Pulse	FCW	Use three 0.160 sec pulses (separated by 0.100 sec) that yield a 3 g/s jerk with a total deceleration of -0.3 g.
Steering Wheel Torque	LCW	Use a single triangle wave at 2.0 Nm of torque with a half-period 0.5 sec. The torque should be applied in the direction needed for recovery.
Steering Wheel Torque	RDCW	Use a single triangle wave at 2.0 Nm of torque with a half-period 0.5 sec. The torque should be applied in the direction needed for recovery.
Steering Wheel Vibration	LCW RDCW	Steering wheel vibration parameters in the following ranges will yield equivalent performance: Frequency 4-12 Hz; Amplitude 1.2-2.2 Nm; Duration 1.2-2.2 sec. *Note: Although some evidence suggests that this display may work, it is not the recommended display for time-critical situations.*
Seat Vibration	RDCW	For LDW systems, use short repeated vibration bursts (mimicking rumble strips) from motors positioned on the side of the seat pan that is towards the direction of vehicle drift. For CSW systems, use a sustain 990 ms vibration from motors positioned towards the front of the seatpan.

Note: Haptic displays also may be used in situations where: 1) the driver is unlikely to hear an auditory display, or 2) multiple alerts are being presented and the use of more than one distinct auditory alert would be confusing to the driver.



Stimulus profiles over time for various haptic warnings



Adapted from References 2, 5, and 8

Discussion

For FCW systems, the recommendations come from a recent study on ICASs, which evaluated a variety of brake-pulse warning parameters (Reference 2). The recommended pulse warnings yielded the best performance in terms of compliance and short braking distance. While these recommended values are in agreement with some brake-pulse guidelines (Reference 3), earlier parametric studies recommend using a brake pulse with different characteristics—e.g., 0.600 second 0.32 g mono-pulse (Reference 4). The data from the intersection collision avoidance study were selected for the current guideline recommendations because that study also evaluated the effectiveness of the alternative 0.600 second mono-pulse signal and found that it yielded significantly worse performance in terms of driver compliance and brake distance.

For LCW systems, steering-wheel torque warnings with the parameters indicated in the guideline recommendation have been shown to be effective in prompting drivers to quickly and consistently cancel unsafe lane changes (Reference 6 and 7). Also, the maximum lateral deviation during a cancelled lane change was found to be significantly less with steering wheel torque than with steering wheel vibrations or no warning at all (Reference 6).

With regard to warnings based on steering wheel vibrations, a parametric study conducted in Reference 5 showed that this type of warning was effective in prompting appropriate corrective actions in Road Departure Warning (RDW) systems and that performance was basically the same for a range of steering wheel vibration parameters indicated in the guideline recommendation. Note, however, that although steering wheel vibrations have been shown to provide some response time advantages under conditions requiring minor steering corrections, they seem to be ineffective when more time-critical responses are required (Reference 5). It should also be noted that 1.2 Nm of amplitude likely represents a minimum acceptable value, because FCW research involving smaller forces found that a 1.0 Nm amplitude was too weak to capture the driver's attention (Reference 6).

Reference 8 used a haptic CCW for an LDW system that was designed to mimic the vibration encountered by crossing a rumble strip, except that it was localized to the side of the seat pan in the direction of the vehicle drift. This study also used a haptic CCW for a CSW system that provided a sustained vibration from two motors located at the front of the seat pan. The results presented in Reference 8 indicate that the haptic in both systems' warnings were very likely to be perceived as attention-getting by most drivers. Drivers also reported that the haptic warnings were not annoying, and that they knew what the warnings meant when they occurred. Furthermore, most drivers also reported that they could easily recognize under which leg the seat vibration was coming from with the LDWs.

Design Issues

The recommendations for the FCW system come from a study on intersection collision warning systems. The recommended characteristics represent the values associated with the haptic signal that yielded the highest level of compliance and the shortest braking distances. It is not known how appropriate the braking profile associated with this warning would be for FCW situations, since the research did not involve a lead vehicle. Therefore, until more definitive research is conducted, care should be taken in using this haptic warning if the overall emphasis of the warning system includes more than fast braking responses.

Cross References

When to Use Haptic Warnings, 5-2
Determining the Appropriate Display Type for Haptic ICWs, 5-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Lee, S.E., Perez, M.A., Doerzaph, Z.R., Brown, S.B., Stone, S.R., Neale, V.L., et al. (2005). *Intersection collision avoidance – violation project: Final project report* (Draft Final Task 5 Report DTNH22-00-C-07007). Washington, DC: National Highway Traffic Safety Administration.
3. Campbell, J.L., Bittner, A.C., Jr., Lloyd, M., Mitchell, E., and Everson, J.H. (1997). *Driver-vehicle interface (DVI) design guidelines for the intersection collision avoidance (ICA) system* (Final Report). Seattle, WA: Battelle Human Factors Transportation Center.
4. Tijerina, L., Johnston, S., Parmer, E., Pham, H.A., and Winterbottom, M.D. (2000). *Preliminary studies in haptic displays for rear-end collision avoidance system and adaptive cruise control system applications* (DOT HS 808(TBD)). Washington, DC: National Highway Traffic Safety Administration.
5. Tijerina, L. Jackson, J., Pomerleau, D., Romano, R., and Petersen, A. (1996). Driving simulator tests of lane departure collision avoidance systems. *Proceedings of ITS America Sixth Annual Meeting, Houston, TX*.
6. Farber, B., Naab, K., and Schumann, J. (1991). *Evaluation of prototype implementation in terms of handling aspects of driving tasks* (Deliverable Report DRIVE V1041/GIDS CON3). Haren, The Netherlands: Traffic Research Institute, University of Groningen.
7. Schumann, J., Godthelp, H., Farber, B., and Wontorra, H. (1993). Breaking up open-loop support for the driver's lateral control task. In A. G. Gale et al. (Eds.) *Vision in Vehicles IV* (pp. 321-332). London: Taylor and Francis.
8. LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, et al. (2006). *Road Departure Crash Warning Field Operational Test*. Washington, DC: National Highway Traffic Safety Administration.

CHAPTER 6. CONTROLS USED IN CWS DEVICES

Selection of Control Type

Introduction

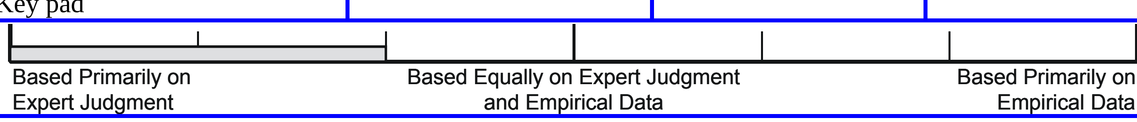
Selection of control type refers to decisions about the apparatus by which the driver makes control inputs—push-buttons, push-pull knobs, rotary knobs (discrete and continuous), levers, slides, thumbwheels, toggle switches, or rocker switches—to the CWS device. Control options include five CWS functions that might be placed under the driver's control. These functions were identified in both empirical studies and design guideline documents. The 1996 COMSIS Guidelines (Reference 1) recommended that each of these functions should be adjustable. Neither the COMSIS Guidelines nor current sources provide much data regarding which control type should be used to implement a given CWS function. The recommendations below are based on the results of empirical studies, discussions and recommendations in guideline documents, and expert judgment.

Design Guidelines

The recommendation column in the table below represents how strongly sources agree that controls should be provided for the CWS function. The third and fourth columns identify control types that may be used for each CWS function. These control types correspond to the candidate controls found below the table. A dash in the third or fourth 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	Recommendation	Use Discrete Control	Use Continuous Control
On/Off Enables and disables the CWS.	Recommended—with reservations	Yes 2-position	No
Auditory Intensity Controls the intensity of the auditory warning display.	Highly Recommended	—	Yes Gross Adjustment
Master Intensity Master control for intensity of visual, auditory, and haptic displays.	Recommended	—	Yes Gross Adjustment
Visual Display Luminance Controls the intensity of the visual warning display.	Highly Recommended	—	Yes Gross Adjustment
Sensitivity (Warning Timing, Warning Threshold, Range, TTC) Controls the physical or temporal proximity threshold for which warnings are activated. This might also apply to ACC gap/headway controls.	Recommended	Yes Multi-Position	Yes Precise Adjustment

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

The COMSIS Guidelines recommend that the driver should be able to manually disable the CWS to avoid the occurrence of false or nuisance alarms. There is some disagreement among sources in the current literature regarding this topic. Reference 2 recommends 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. Reference 3 takes 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. (Reference 3 does concede, however, that without a Federal mandate, vehicle manufacturers may elect to allow drivers to disable the FCW in order to avoid nuisance alarms.)

Almost all sources recommend that controls be provided for adjusting both auditory warning intensity and visual warning display luminance. However, one source recommends that alarms should not be adjustable or defeatable, but that other auditory display systems (e.g., radio, navigation system) should not be capable of producing uncontrollable volume levels that mask interior or exterior alarms (Reference 4). No sources disagree with the COMSIS recommendation that a Master Intensity control may be provided.

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 prefer to 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) (Reference 5). Nonetheless, these adjustments have been successfully implemented in empirical studies. In Reference 6, drivers used the full range of these adjustments (six discrete values each for headway and warning timing). In addition, drivers 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 Reference 7, three transit bus operators also 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 optimize reaction times.

The majority of recent studies and discussion about CWS control has focused on what controls to provide. 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.

Design Issues

Controls for crash avoidance systems can be categorized into two classes: discrete controls and continuous controls. 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). Many CWS controls, however, may be implemented using either class of control. For example, Reference 8 recommends that Warning Timing should be adjusted with a rotary control, slide, or thumbwheel control that is either discrete or continuous. The designer must determine which class of control will most benefit the driver while best fitting the overall vehicle control strategy.

Cross References

Specific Guidelines for Control Design, 6-10

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Pomerleau, D., Jochem, T., Thorpe, C., Batavia, P., Pape, D., Hadden, J., et al. (1999). *Run-Off-Road Collision Avoidance Using IVHS Countermeasures, Final Report* (DOT HS 809 170). Washington, DC: National Highway Traffic Safety Administration.
3. Wilson, T., Miller, S., Burns, M., Chase, C., Taylor, D., Butler, W., et al. (1998). *Light vehicle forward-looking, rear-end collision warning system performance guidelines* (DOT HS 808 948).Washington, DC: National Highway Traffic Safety Administration.
4. Japan Automobile Manufacturers Association (JAMA). (2004b). *JAMA guidelines for in-vehicle display systems—version 3.0*. Tokyo: Author.
5. Campbell, J.L., Hooey, B.H., Carney, C., Hanowski, R J., Gore, B.F., Kantowitz, B.H., et al. (1996). *Investigation of alternative displays for side collision avoidance systems* (Final Report). Seattle, WA: Battelle Seattle Research Center.
6. General Motors Corporation. (2005). *Automotive Collision Avoidance System Field Operational Test (ACAS FOT) Final Program Report* (DOT HS 809 886). Washington, DC: National Highway Traffic Safety Administration.
7. University of California PATH and Carnegie Mellon University Robotics Institute. (2006). *Integrated Collision Warning System Final Evaluation Report*. Washington, DC: Federal Transit Administration.
8. Kiefer, R., LeBlanc, D., Palmer, M. Salinger, J., Deering, R. and Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (Final Report DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.

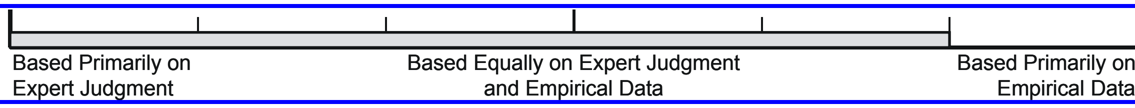
Control Movement Compatibility

Introduction

Control movement compatibility refers to the expected relationships between control activation movements and the corresponding changes in the system being controlled and any associated displays. The 1996 COMSIS Guidelines (Reference 1) did not address compatibility of controls in any detail. However, information on this topic is available from other sources.

Design Guidelines

- Control movements should correspond to the expectations of the user. See the table below for recommended control-movement to system-function relationships.
- Choose the strongest control-movement to system-function relationship when multiple relationship options exist in 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 not adversely affect the driver's ability to use the system.

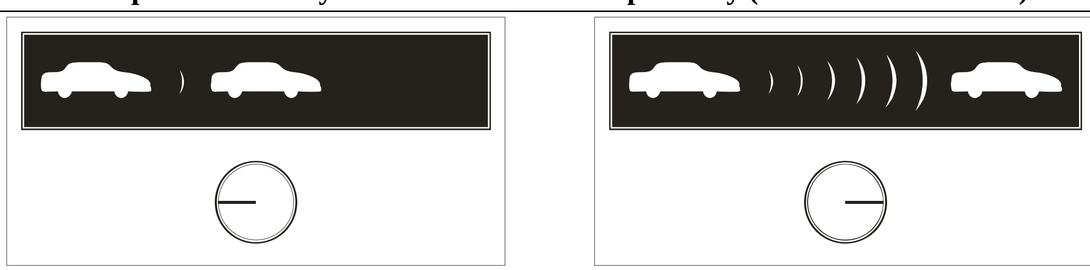


Recommended control-movement to system-function relationships

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

From Reference 2

Example of sensitivity control movement compatibility (clockwise to increase)



A. Minimum Sensitivity **B. Maximum Sensitivity**

Adapted from Reference 6

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

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. 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 (References 2 and 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 (Reference 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. Reference 2 provides an example of 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 principles apply when designing controls with associated linear displays (e.g., a gap indicator, FCW warning timing threshold). Strong stereotypes result when all three principals are combined. These principals are listed as follows (Reference 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

Selection of Control Type, 6-2
Labels for Controls, 6-8

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Campbell, J.L., Carney, C., and Kantowitz, B.H. (1998). *Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO)*, (FHWA-RD-98-057). Washington, DC: Federal Highway Administration.
3. International Organization for Standardization (ISO). (2005). *Road vehicles – Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems* (ISO/TR 16532). Geneva, Switzerland: International Organization of Standards.
4. Wilson, T., Miller, S., Burns, M., Chase, C., Taylor, D., Butler, W., et al. (1998). *Light vehicle forward-looking, rear-end collision warning system performance guidelines* (DOT HS 808 948).Washington, DC: National Highway Traffic Safety Administration.
5. Boff, K.R., and Lincoln, J.E. (Eds.). (1988). *Engineering data compendium: Human perception and performance*. Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory.
6. General Motors Corporation. (2005). *Automotive Collision Avoidance System Field Operational Test (ACAS FOT) Final Program Report* (DOT HS 809 886). Washington, DC: National Highway Traffic Safety Administration.

Control Coding

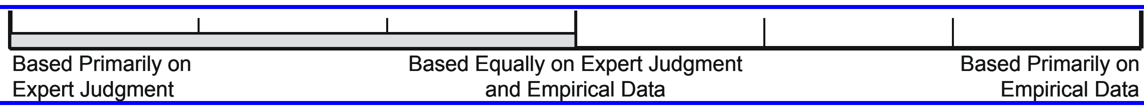
Introduction

Control coding refers to the design characteristics of controls that serve to identify the control or to identify the relationship between the control and the function to be controlled. Proper coding of controls will increase the probability that the controls will be quickly and accurately located by drivers, thus reducing the eyes-off-road time. The 1996 COMSIS Guidelines (Reference 1) discussed four methods of coding that are likely to be effective for automotive applications: shape, size, and texture coding, and labeling. Data from additional sources are consistent with the COMSIS Guidelines and provide additional information regarding location coding. These guidelines address location, shape, size, and texture coding; label coding is discussed separately on page 6-8.

Design Guidelines

Use one or more of the following design characteristics to identify controls:

- Location Coding: In order to ensure discriminable and unique control locations, controls must 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

Advantages	Type of coding				
	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).					●

Adapted from Reference 5

Discussion

Several sources provide information about spacing and location of controls (e.g., References 2, 3, and 4). In particular, Reference 4 provides a useful table that summarizes minimum control separation distances for various types of controls. In addition, Reference 5 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.

The 1996 COMSIS Guidelines recommend that controls for different functions should 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 for coding as shape coding. However, size coding is most appropriate in applications using ganged controls. Reference 5 recommends that no more than three different sizes should be used when coding for absolute size. In addition, knob diameters should differ by at least 1.27 cm (0.5 in) and knob thicknesses should be greater than 10mm (0.4 in) to make them discriminable.

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 (References 3 and 4).

Design Issues

When several controls are similar, they may be difficult to discriminate unless they are separated by an adequate distance. Reference 3 cites 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 (Reference 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. However, smooth knobs can still be discriminated from other texture types while wearing gloves (Reference 2).

Cross References

Labels for Controls, 6-8

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Boff, K.R., and Lincoln, J.E. (Eds.). (1988). *Engineering data compendium: Human perception and performance*. Wright-Patterson Air Force Base, OH: Armstrong Aerospace Medical Research Laboratory.
3. Sanders, M.S., and McCormick, E.J. (1993). *Human factors in engineering and design* (7th ed.). New York: McGraw-Hill.
4. Campbell, J.L., Carney, C., and Kantowitz, B.H. (1998). *Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO)* (FHWA-RD-98-057). Washington, DC: Federal Highway Administration.
5. MIL-STD-1472F. (1998). *Human engineering*. Washington, DC: Department of Defense.

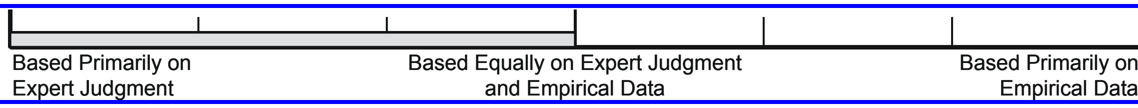
Labels for Controls

Introduction

Labels for controls refers to identifying controls and control settings using text or symbolic markings. The 1996 COMSIS Guidelines (Reference 1) provided general guidance regarding intelligibility, conspicuity, presentation type (i.e., textual versus symbolic), and orientation of labels for controls. Other sources support the results found in the COMSIS Guidelines. Also, they provide additional information about how standardization and presentation type can be used to improve the recognition and comprehension of controls and their corresponding settings. The diagrams below illustrate examples of both well-designed and poorly-designed labels for identifying controls and their settings. The well-designed labeling methods presented below provide a basis for developing effective labeling strategies.

Design Guidelines

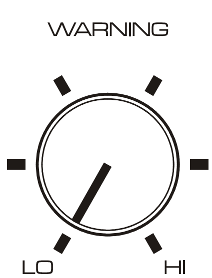
- Controls should be clearly labeled to identify their functions and settings.
- Labels should be visible and recognizable before the driver reaches for the control. The label should be located such that the driver's hand will not cover the label when reaching for the control.
- Where appropriate, use international standards or recognized industry practice related to icons, legibility, words, acronyms, etc. when labeling controls and their settings (e.g., see MIL-STD-1472F; ISO, 2000, etc.).
- Icons are preferred for representing both settings and functionality. Use icons to represent numerical values that may have little or no meaning for the driver.



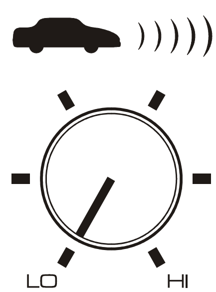
Examples of labels for various types of controls

Forward Collision Warning Sensitivity

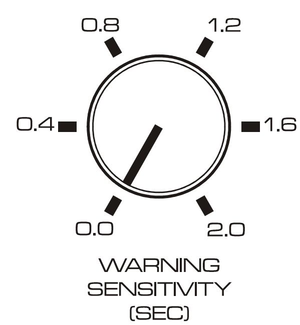
Preferred



OR



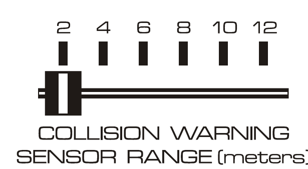
Not Preferred



Side Collision Warning Sensor Range

Preferred

Not Preferred



Adapted from References 5, 6, and 7

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 (Reference 2). 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. In applications for which no standards exist, relevant design guidelines or empirical data should be used to determine the appropriate strategy for control labeling (Reference 3).

Design Issues

One way to improve comprehension of control function and setting is by labeling the controls in a manner that is consistent with population stereotypes for control-display relationships (References 4 and 5). In many systems, such as warning timing adjustments, numerical values for control settings will have little meaning for 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 (Reference 5).

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 condenses forms, an important consideration in applications where the amount of available space is limited (References 4 and 6).

Text and symbols may be combined to improve comprehension of the control function and settings. For example, Reference 7 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 Reference 6).

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 (References 2).

Cross References

Control Coding, 6-6
Specific Guidelines for Control Design, 6-10

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Sanders, M.S., and McCormick, E.J. (1993). *Human factors in engineering and design* (7th ed.). New York: McGraw-Hill.
3. Alliance of Automobile Manufacturers. (2002). *Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems, Version 2.0* (Report of the Driver Focus-Telematics Working Group). Southfield, MI: Author.
4. Kiefer, R., LeBlanc, D., Palmer, M. Salinger, J., Deering, R., and Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (Final Report DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.
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6. Campbell, J.L., Richman, J.B., Carney, C., and Lee, J.D. (2002). *In-vehicle display icons and other information elements. Task F: Final in-vehicle symbol guidelines* (FHWA-RD-03-065). Washington, DC: Federal Highway Administration.
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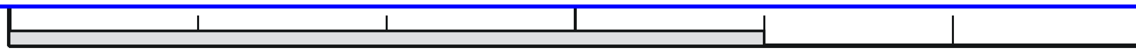
Specific Guidelines for Design of CWS Controls

Introduction

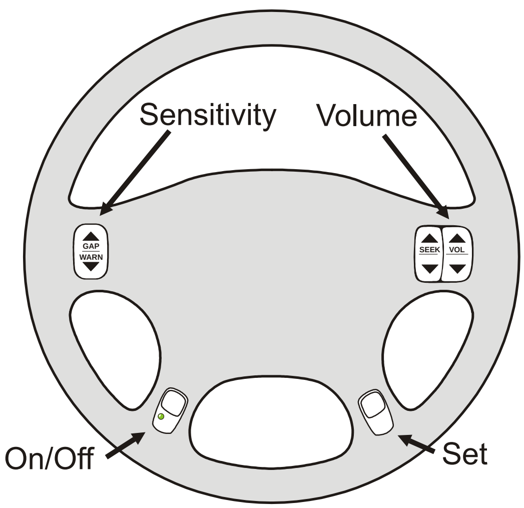
Specific guidelines for design of controls refers to safety and ergonomic aspects of control design that are defined by the relationship between the CWS controls and the primary driving controls and displays. The 1996 COMSIS Guidelines (Reference 1) provide sparse information regarding this topic. Current sources provide additional information that is useful for designing controls that are safe to operate. Note that guidelines related to control placement are closely linked to position coding of controls (see page 6-6); placement of controls for ease of accessibility may also serve to aid in identifying the control. Nonetheless, these guidelines are specifically oriented toward operability rather than identification.

Design Guidelines

- CWS controls should not adversely affect or interfere with other critical system components or primary driving controls.
- Controls should be aligned as closely as possible to the forward view in order to reduce glance times.
- Controls should be designed so that the driver can keep one hand on the steering wheel at all times.
- Manual adjustment of CWS controls should not result in significant distraction of driver attention from the driving task.



Examples of well-designed and poorly-designed control placement

<table>
<tr><th>A. Well-designed Control Placement</th><th>B. Poorly-designed Control Placement</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>• Controls are aligned with forward view
• Controls are within fingertip reach
• Higher priority controls are on the outside (easier to manipulate)
• Controls can be activated with both hands on the wheel
• Controls are coded by location for easy identification
Adapted from Reference 6</td><td>• Controls are not aligned with the forward view (driver must look away and down to see controls and display)
• Placement requires increased glance time
• Controls are partially obscured by steering wheel
• Driver must reach to operate control
• Controls are poorly or not labeled
• Inappropriate control type for on/off switch</td></tr>
</table>

Discussion

The 1996 COMSIS Guidelines (Reference 1) recommend that controls be designed to be compatible with normal driving. In addition, the purpose and operation of controls should be obvious. Current sources agree that the application and placement of CWS controls must not interfere with the primary task of driving the vehicle. CWS controls that are easy to understand and to adjust reduce the level of distraction from the driving task. However, 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 (References 2 and 3).

Design Issues

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. In addition, CWS interactions should be designed to require that only one hand at a time needs to be removed from the steering wheel (Reference 3).

The operation of a CWS control must not adversely affect the operation of a primary driving control. Reference 3 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.

Frequently used controls should be placed within easy reach and in alignment with the forward view in order to reduce glance times. In addition, controls that require lengthy interactions should be placed within 30 degrees of the driver's normal field of view (References 3, 5, and 4). In field operational tests of FWC and 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 are easier to manipulate (Reference 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 what the driver expects.

Complex interactions, such as initial control settings, should be reserved for times when the vehicle is stopped. One way to prevent certain interactions when the vehicle is moving is to use variable-function keys (i.e., keys that are mapped to more than one function based on context) on a keypad or touch-screen. Because 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 (References 2 and 7).

Cross References

Control Movement Compatibility, 6-4
Control Coding, 6-6

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Pomerleau, D., Jochem, T., Thorpe, C., Batavia, P., Pape, D., Hadden, J., et al. (1999). *Run-Off-Road Collision Avoidance Using IVHS Countermeasure, Final Report* (DOT HS 809 170). Washington, DC: National Highway Traffic Safety Administration.
3. Stevens, A., Hallen, H., Pauzie, A., Vezier, B., Gelau, C., Eckstein, L., et al. (2005). *European statement of principles on the design of human machine interaction* (ESoP 2005, Draft). Directorate-General Information Society Technologies and Media of the European Commission.
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5. International Organization for Standardization (ISO). (2005). *Road vehicles – Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems* (ISO/TR 16532). Geneva, Switzerland: International Organization of Standards.
6. General Motors Corporation. (2005). *Automotive Collision Avoidance System Field Operational Test (ACAS FOT) Final Program Report* (DOT HS 809 886). Washington, DC: National Highway Traffic Safety Administration.
7. Campbell, J.L., Carney, C., and Kantowitz, B.H. (1998). *Human factors design guidelines for advanced traveler information systems (ATIS) and commercial vehicle operations (CVO)* (FHWA-RD-98-057). Washington, DC: Federal Highway Administration.

CHAPTER 7. FORWARD COLLISION WARNING SYSTEMS

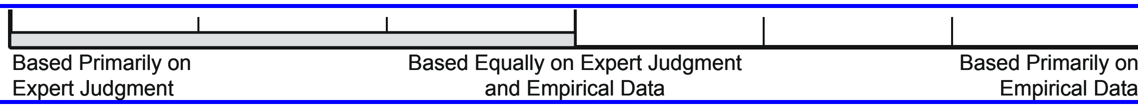
Design of ICWs for FCW Systems

Introduction

The design of ICWs describes the broad functional requirements of the ICWs for FCW systems as they relate to how drivers experience and interact with the system. The 1996 COMSIS Guidelines cover ICW timing, control of false alarms, and detection zone coverage in detail (Reference 1). The current guideline expands on these topics, and reflects empirical data that have been obtained since the COMSIS work.

Design Guidelines

- The ICW should be a multimodal display consisting of a primary auditory warning supplemented by a conspicuous visual warning.
- Using an “early” warning presentation timing is recommended over “late” warning timing.
- ICW false alarms should be limited to less than once per week for in-path and less than once per week for out-of-path false alarms.
- If FCW system function is compromised by mechanical or environmental factors, drivers must be informed that the system is not operational.



Desired general characteristics of ICWs in FCW systems.

An FCW ICW should:

- Be usable by naïve drivers in mass marketed passenger vehicles.
- Meet or match the driver’s mental model.
- Be intuitive.
- Not confuse the driver.
- Not annoy the driver.
- Aid the driver’s understanding of system operations.
- Focus the driver’s attention on the hazard ahead.
- Elicit an automatic or conditioned response.
- Be clearly conspicuous and easy to perceive under all driving conditions.
- Be distinguishable from other types of collision warnings.
- Not cause other collisions to occur.
- Not embarrass the driver.
- Not promote risk taking by the driver.
- Not compromise the driver’s ability to override the system and perform other avoidance actions, such as braking, steering, or accelerating.

Adapted from Reference 2

Discussion

Display modality: Multi-modal signals provide greater opportunities for drivers to detect the warning signal. Auditory (recommended) or haptic signals (not strongly recommended) should be used as the primary signal, because these warnings are omnidirectional and drivers can detect them even if they are looking away from the roadway (References 2 and 3). Also, the addition of a visual warning can provide a "back-up" communication channel if there is high ambient noise/vibration or if a driver is hearing impaired (Reference 3).

Warning timing: Specific recommendations for timing parameters are beyond the scope of the current guideline, since they vary depending on the algorithm used, the situation addressed (e.g., decelerating versus stopped lead vehicle) and vehicle operational characteristics. At a general level, however, the available research indicates that drivers benefit more from earlier warnings than later warnings. In particular, early warning ICWs lead to faster driver responses, longer TTC values, and are also associated with higher levels of driver trust (References 4 and 5). Early warnings are also more effective than late warnings for reducing the number and severity of crashes (Reference 6). In addition, late warnings may actually distract drivers while they are planning or executing evasive maneuvers and may lead to more crashes (Reference 5).

In terms of general aspects of warning timing, Reference 3 proposes using a zone of acceptable ICW onset timing. The early end of the zone is likely to be adjustable and should be focused on driver preference considerations (e.g., balancing warning benefits with false-alarm rates). The late end of the zone (especially the zone cut-off boundary) should be focused on the braking capabilities of drivers/vehicles under various kinematic situations.

*False Alarms***:** The recommended false-alarm rates of less than once per week for in-path and less than once per week for out-of-path false alarms is based on the recommended value from Reference 3, and refers to conditions under which the system is set (either by default or by the driver) to provide generally late warnings. This recommendation is based on expert judgment in conjunction with consideration of the limited available empirical data.

The key problems with high false-alarm rates are driver annoyance and performance decrements associated with loss of trust in the system (References 3 and 7). Importantly, the available field data suggest that false alarms rarely cause drivers to reflexively brake in an unnecessary and dangerous manner because drivers take the broader driving context into account (Reference 7). However, if a FCW system generates a high number of false alarms, it may be beneficial to allow drivers to temporarily disable the ICW because the intrusiveness of the alarm will likely cause annoyance and could also be unnecessarily distracting. Note that if this capability is provided, Reference 3 recommends that the ICW be automatically re-engaged at the beginning of the next ignition cycle.

Design Issues

Although warning timing is a significant factor leading to false alarms, detection-zone coverage area and specific driver situations addressed by the FCW system (e.g., distracted driver versus longer headway promotion) are two other implementation aspects that can greatly affect false alarm generation under actual roadway conditions (Reference 7). Reference 3 (pg. 4-48 to 4-71) provides detailed guidance on the appropriate detection-zone and driver-situation coverage.

Cross References

How to Prevent False or Nuisance Warnings, 2-10
Design of CCWs for FCW Systems, 7-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Wilson, T., Miller, S., Burns, M., Chase, C., Taylor, D., Butler, W., et al. (1998). *Light vehicle forward-looking, rear-end collision warning system performance guidelines* (DOT HS 808 948).Washington, DC: National Highway Traffic Safety Administration.
3. Kiefer, R., LeBlanc, D., Palmer, M. Salinger, J., Deering, R. and Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (Final Report DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.
4. Abe, G. and Richardson, J. (2004). The human factors of collision warning systems: System performance, alarm timing, and driver trust. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 2232-2236.
5. McGehee, D.V., Brown, T.L., Wilson, T.B., and Burns, M. (1997). *Examination of Driver's Collision Avoidance Behavior in a Lead Vehicle Stopped Scenario Using a Front-to-Rear-End Collision Warning System* (DTNH22-93-C-07326). Washington, DC: National Highway Traffic Safety Administration.
6. Lee, J.D., McGehee, D.V., Brown, T.L., and Reyes, M.L. (2002). Driver distraction, warning algorithm parameters, and driver response to imminent rear-end collisions in a high-fidelity driving simulator (DOT HS 809 448). Washington DC: National Highway Traffic Safety Administration.
7. General Motors Corporation. (2005). *Automotive Collision Avoidance System Field Operational Test (ACAS FOT) Final Program Report* (DOT HS 809 886). Washington, DC: National Highway Traffic Safety Administration.

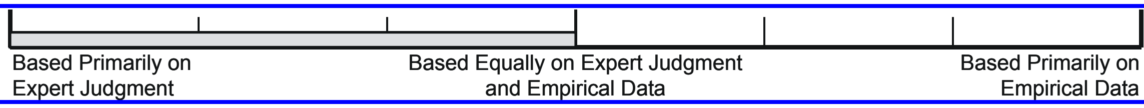
Design of CCWs for FCW Systems

Introduction

The design of CCWs describes the broad functional requirements of the CCWs for FCW systems as they relate to how drivers experience and interact with the system. The 1996 COMSIS Guidelines cover CCW timing, basic display requirements and control of false alarms (Reference 1). The current guidelines expand on these topics, and reflect data that have been obtained since the COMSIS work.

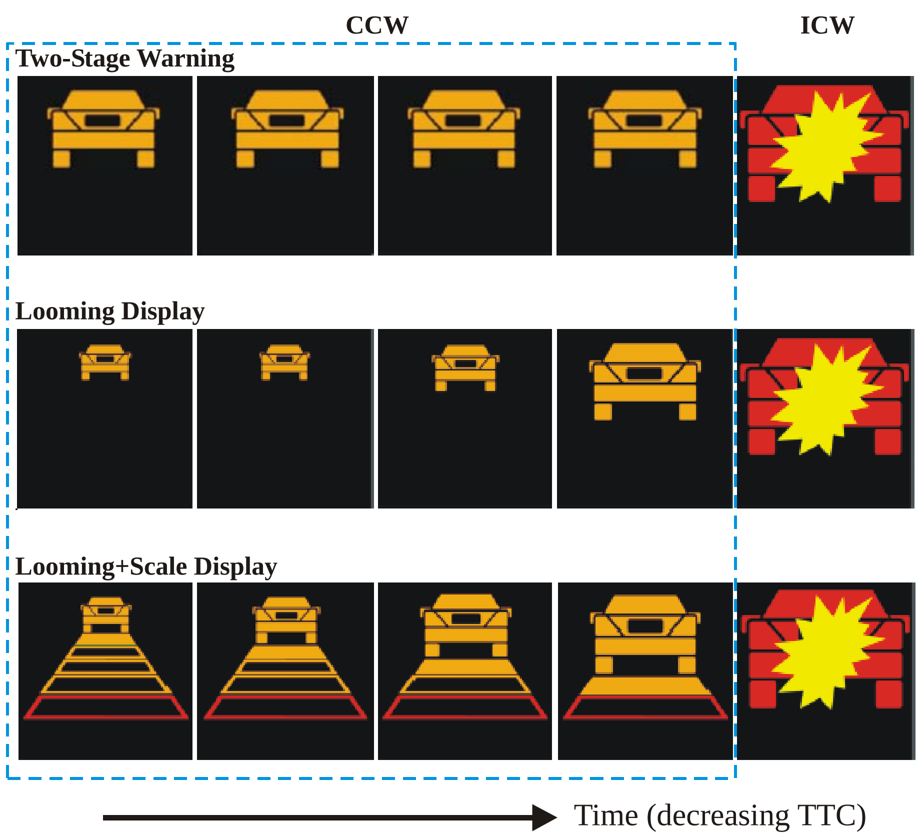
Design Guidelines

- The CCW should consist of an easily perceived, yet not highly intrusive visual-only display (e.g., it should not flash).
- The CCW should be implemented as either a looming/looming+scale display or as a discrete two-stage display.
- CCW detection zone and crash situation coverage should be the same as that associated with the ICW implemented in the same system.
- Drivers should be provided the capability of adjusting the sensitivity of the CCW component, including the ability to turn off this warning mode to help manage false alarms.



Desired general characteristics of CCWs in FCW systems

The figure below shows examples of two-stage, looming and looming + scale displays.



Adapted from Reference 2

Discussion

While using a CCW is not a generally recommended approach for FCW systems (see guideline on page 2-2), it may be appropriate if the overall design goal is to promote longer driving headways.

The CCW should consist solely of a visual display because auditory and haptic CCWs are highly intrusive, which makes them likely to become annoying to drivers since these alarms would occur relatively frequently (References 1 and 3). Also, reserving the auditory warning for the ICWs will make them "stand out" more and help promote a clear association between the ICW auditory signal and the imminent crash situation. Similarly, although the CCW should be easily visible (see pages 4-8 and 4-10), it must also be clearly distinguishable from the ICW. For example, in Reference 4, a CCW that was identical to the ICW except that it did not flash appeared to reduce the overall effectiveness of the ICW.

The CCW should be implemented as either a looming/looming+scale display or as a discrete two-stage display. The figure on the previous page provides examples of looming/looming+scale and two-stage displays that were similar to those implemented as part of effective FCW system displays in driving simulator or on-road studies (References 2, 5, and 6). Note, however, that the evidence showing that these displays are effective in increasing driver headway is not strong, and also that these benefits may be limited to specific driving situations (e.g., limited access roads in the daytime; see also Reference 6).

The CCW detection zone and crash situation coverage should be the same as with the ICW in order to help drivers develop and maintain a consistent mental model for the CWS device (Reference 3). The only difference between CCW and ICW conditions should be the timing parameters.

Design Issues

There are no clear data on what is an acceptable false-alarm rate for CCWs. However, two types of false alarms are particularly relevant for this type of warning. The first are false alarms that do not represent potential forward hazards (e.g., out-of path hazards) and the second are those related to warning timing (e.g., premature warning). The first type of false alarms should be addressed in the same manner as ICWs and using the same detection algorithms should largely address this problem (Reference 4). False alarms arising from premature warnings timing may be addressed by allowing drivers to adjust the sensitivity of the warning timing and also by allowing them to turn off CCWs completely (Reference 4 and 6). This adjustment should be made independently of any allowable adjustments to ICW timing, and this fact should be clear to the driver in both the interface and functionality of the adjustment controls (Reference 4).

Cross References

How to Select the Number of Warning Stages, 2-2
Design of ICWs for FCW Systems, 7-2

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. General Motors Corporation and Delphi-Delco Electronic Systems. (2002). *Automotive collision avoidance system field operation test, warning cue implementation summary report* (DOT HS 809 462). Washington, DC: National Highway Traffic Safety Administration.
3. Wilson, T., Miller, S., Burns, M., Chase, C., Taylor, D., Butler, W., et al. (1998). *Light vehicle forward-looking, rear-end collision warning system performance guidelines* (DOT HS 808 948).Washington, DC: National Highway Traffic Safety Administration.
4. Kiefer, R., LeBlanc, D., Palmer, M. Salinger, J., Deering, R. and Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (Final Report DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.
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6. General Motors Corporation. (2005). *Automotive Collision Avoidance System Field Operational Test (ACAS FOT) Final Program Report* (DOT HS 809 886). Washington, DC: National Highway Traffic Safety Administration.
7. Wilson, T., Miller, S., Burns, M., Chase, C., Taylor, D., Butler, W., et al. (1998). *Light vehicle forward-looking, rear-end collision warning system performance guidelines* (DOT HS 808 948).Washington, DC: National Highway Traffic Safety Administration.

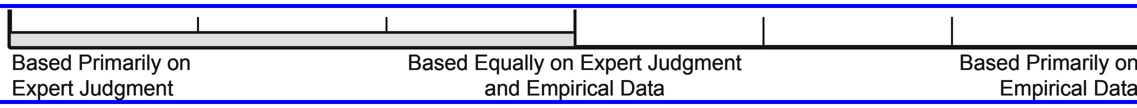
Design of Visual, Auditory, and Haptic Warnings for ICWs

Introduction

The design of ICWs describes the general characteristics that ICWs for FCW systems should have in order to maximize their ability to warn drivers about the imminent collision situation. The 1996 COMSIS Guidelines provide limited information about the location and characteristics of the visual warning and only brief recommendations for auditory and haptic warnings (Reference 1). The current guidelines expand on these topics, and reflect data that have been obtained since the COMSIS work.

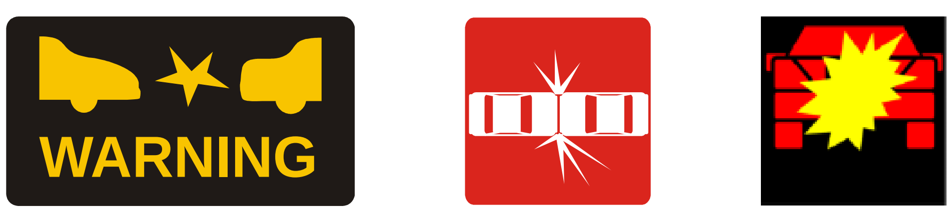
Design Guidelines

- ICWs should consist of a conspicuous and urgent-sounding auditory signal in conjunction with a flashing visual icon symbol/icon display presented near the forward line of site.
- The recommended auditory alert is the CAMP sound #8 (Reference 2) presented from a forward speaker at around 75 dB.
- The recommended visual alert is a symbol/icon display presented on a HUD or high head-down display (HHDD) directly in front of the driver.
- Haptic ICWs are not recommended at this time, unless the driving situation is such that the driver will not hear an auditory warning or if multiple alerts are being presented simultaneously.



Visual ICW icons used as part of an effective FCW system.

The figure below shows three different FCW system ICWs employed in References 2, 3, and 4, respectively.



Discussion

The CAMP non-speech warning alert (Reference 2; sound #8) is the recommended auditory warning because it is the sound that has received the most extensive testing and has been shown to be effective in alerting distracted drivers (References 2, 3, and 4). A volume level of around 75 dB is recommended because it was found to be effective in previous tests (References 2, 3, and 4). Also, Reference 4 investigated a range of warning volumes and found that the CAMP auditory alert was equally effective when presented with a range of 64.8 to 84.8 dB (against a background of 67-72 dBa ambient vehicle noise), and that none of the volume levels were associated with significant startling of drivers (Reference 4). This study also notes that higher volumes levels may be less appropriate because they risk being more annoying without providing additional performance benefits. Finally, the auditory warning should be presented from a speaker positioned in front of the driver so that the driver's attention will be oriented towards the forward driving scene. Note that virtual speaker locations should be avoided because they are associated with generally poorer spatial localization (Reference 5).

The recommended visual display is a symbol/icon stimulus that is easily recognized as an FCW indicator. The figure on the previous page presents examples of symbol/icon displays that have been effectively used in previous research (References 2, 3, 4, and 6). Although a predominantly red display is recommended because this color is associated with high criticality/danger information, Reference 2 recommends using an amber/yellow or orange display—especially with a single-stage FCW system—if there is the potential for confusion with other red dashboard telltales (e.g., emergency brake; see also the guideline on page 4-3). Other aspects of the visual display, such as size, luminance, and contrast, should be consistent with the guideline presented on page 4-10.

Both HHDDs and HUDs have been successfully used in test systems (References 2, 3, and 4), and a direct comparison of both systems found no significant difference between the two in terms of driver performance (Reference 2). The HHDD used in Reference 4 was positioned approximately 0.95 m in front of the driver and 7.7 degrees down from the central viewing point. The HUD images evaluated were positioned approximately 0.95 to 1.20 m in front of the driver and 4–6 degrees down from the central viewing point (References 2, 3, and 4). Using a low head-down display (LHDD) (e.g., dashboard, instrument panel, center stack) is not recommended because these locations are less effective in drawing driver glances (Reference 7). Also, if drivers do look at them, then the LHDDs pull the driver's gaze away from the forward view where it is needed.

Haptic displays in general, and brake pulse warnings in particular, are not recommended for a variety of reasons covered in the guideline presented on page 5-2. However, another FCW-specific reason for not employing brake pulses is to avoid problems if ICW false-alarm rates are significant. For example, in Reference 6, ICW false-alarm rates were near 70 percent, which means that using brake pulse warnings could likely cause vehicle deceleration at unexpected and inappropriate times.

Design Issues

False alarm-rates for ICWs should be considered when determining ICW characteristics. In particular, with developing systems, ICW false alarm rates could be higher than desirable (e.g., more than once per week), so it may be necessary to consider using an ICW with less obtrusive characteristics to limit driver annoyance (Reference 6).

Cross References

General Characteristics of Visual ICWs and CCWs, 4-10
When to Use Haptic Warnings, 5-2
Design of ICWs for FCW Systems, 7-2

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Kiefer, R., LeBlanc, D., Palmer, M. Salinger, J., Deering, R. and Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (Final Report DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.
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4. Lee, J.D., McGehee, D.V., Brown, T.L., and Reyes, M.L. (2002). *Driver distraction, warning algorithm parameters, and driver response to imminent rear-end collisions in a high-fidelity driving simulator* (DOT HS 809 448). Washington DC: National Highway Traffic Safety Administration.
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6. General Motors Corporation. (2005). *Automotive Collision Avoidance System Field Operational Test (ACAS FOT) Final Program Report* (DOT HS 809 886). Washington, DC: National Highway Safety Administration.
7. Grant, B.S., Kiefer, R.J., and Wierwille, W.W. (1995). Drivers' detection and identification of head-up versus head-down telltale warnings in automobiles. *Proceedings of the Human Factors Society 39th Annual Meeting.*

CHAPTER 8. LANE CHANGE WARNING SYSTEMS

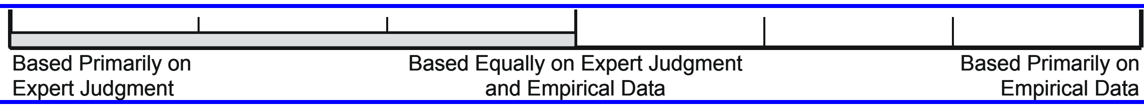
Design of ICWs for LCW Systems

Introduction

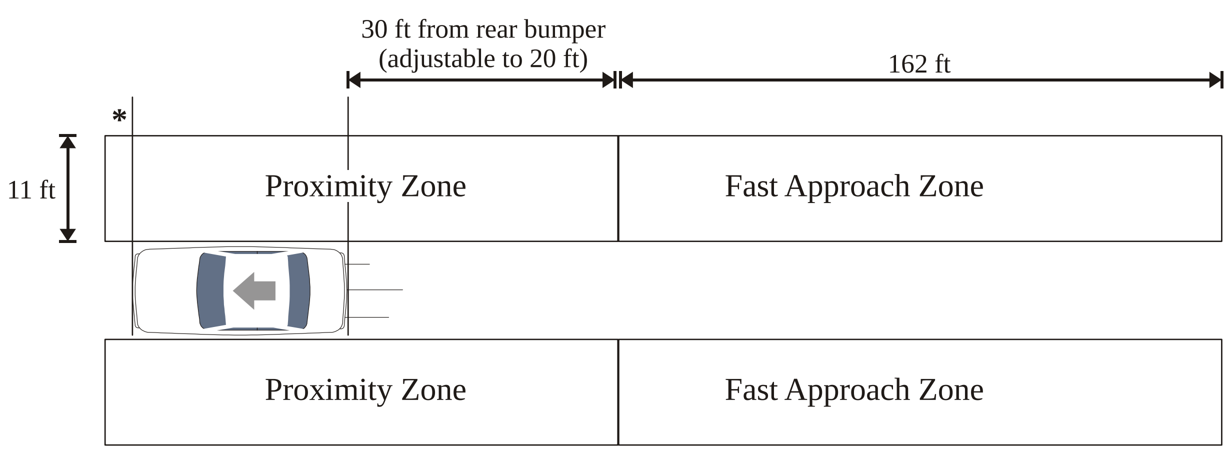
The design of ICWs describes the broad functional requirements of ICWs for LCW systems as they relate to how drivers experience and interact with the system. The 1996 COMSIS Guidelines cover ICW presentation conditions, display format, and detection zone coverage in detail (Reference 1). Most of the information from the 1996 COMSIS Guidelines is still applicable because there has been relatively little research on LCW systems since then.

Design Guidelines

- If ICW false-alarm rates can be kept low, then the ICW should be a multimodal display consisting of a conspicuous visual signal supplemented by a concurrent auditory warning.
- The ICW should be presented when the system predicts that: 1) a lane change is about to occur and 2) that it can result in a collision.
- The detection zone should encompass the driver's entire blind spot, up to a full lane on either side of the vehicle (see figure below for dimensions).
- ICW false alarms should be limited to less than once per week.
- If LCW system function is compromised by mechanical or environmental factors, drivers must be informed that the system is not operational.



Vehicle detection zones (recommended in Reference 5)



Any vehicle the size of a bicycle or larger should be detected in either zone.

* Reference 5 found that extending the proximity zone in front of the vehicle was useful, however, the precise distance is yet to be determined.

The figure above provides information about the spatial extent of the recommended LCW system detection area. The area is divided into separate "proximity" and "fast approach" zones. The proximity zone includes the driver's blind spot and is the primary area in which an adjacent vehicle will trigger a warning. The fast approach zone is used to trigger alerts for adjacent vehicles with high relative speeds that are expected to be in the proximity zone in time to conflict with the driver's vehicle.

Discussion

Display modality: Multi-modal signals provide greater opportunities for drivers to detect the warning signal. The primary warning display should be a conspicuous visual warning that provides information in locations where drivers are likely to be looking as they initiate a lane change (e.g., rear-view or side-view mirrors; see guideline on page 8-6). As long as ICW false-alarm rates are minimal, then a concurrent auditory signal is also recommended (References 2 and 3), primarily because drivers may not always look at the side-view or rear-view mirrors before changing lanes (Reference 4) and the omnidirectional auditory warning will alert drivers regardless of where they are looking. With high false-alarm rates, an auditory warning may be overly obtrusive and lead to driver annoyance. In this case, a visual-only signal should be considered. Haptic warning signals also may be applicable (see guideline on page 8-6).

Warning Conditions: The recommendation that the ICW be based on the driver's intent to change lanes assumes that the system is able to detect an intended lane change even if the turn signal is not activated. This capability is desirable because drivers do not always activate their signal before turning, and some drivers consistently activate their signal only after the lane change is already in progress (References 1 and 4). Also, Reference 4 found that only 20-30% of drivers activated their turn signals when changing lanes under imminent crash or time-critical conditions (e.g., to avoid another vehicle).

If the system lacks the capability to determine the driver's intent to change lanes, then basing the ICW on turn signal activation is the best alternative given that signal activation is a reasonably good predictor of lane changes (References 2 and 5). Based on limited field testing of this type of system (Reference 5), a turn-signal-activated ICW was rated as being helpful in notifying drivers about potential conflicts. However, there is insufficient driver performance data to make conclusions about the relative safety of this approach. Note, also, that the general approach taken with the system evaluated in Reference 5 was somewhat different, with more of an emphasis on the LCW system as a tool to augment driver situation awareness rather than as a strict warning system, and this may have affected driver opinions about system effectiveness.

False Alarms: It should be noted that there are very little data regarding acceptable ICW false-alarm rates for LCW systems, and the recommended value of less than once per week is based on expert-judgment recommendations for FCW systems (Reference 6).

The system investigated in Reference 5 had very high false-alarm rates (42 per hour for both ICW and CCW combined) and drivers generally reported that this level was acceptable. Many of these false alarms likely went unnoticed, however, because the warning displays were unobtrusive and a high proportion of them occurred when drivers were unlikely to make lane changes and did not need to use their mirrors.

Design Issues

The display recommendations are based on driver lane-change behavior without experience with LCW systems and may overemphasize the need to compensate for drivers who may not always check their mirrors before changing lanes. It is possible that providing LCW system information to drivers may change their behavior so that they consistently rely on and use LCW visual displays. In this case, less obtrusive visual-only displays would be sufficient.

In a related issue, the recommendations regarding the definition of ICW conditions is also based on driver behavior without the system and may overemphasize the need to compensate for drivers who do not activate their turn signal or activate it after initiating the lane change. Again, it is possible that drivers could change their behavior to take advantage of the LCW information. See Reference 5 for further discussion of the rationale and assumptions associated with this "parallel usage" conceptualization of LCW systems.

If a LCW system is implemented with ICW conditions defined only by turn-signal activation, then consideration should be given to using either a visual-only display or to providing drivers with some type of easily accessible manual override option. The reason for this is that some drivers may frequently encounter situations in which they deliberately signal a lane change before an adequate gap is available (which would be sufficient to trigger an ICW), resulting in nuisance alarms (see Tutorial 2).

Cross References

How to Prevent False or Nuisance Warnings, 2-10
Design of CCWs for LCW Systems, 8-4
Design of Visual, Auditory, and Haptic Warnings for LCW Systems, 8-6

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Olsen, E.C.B. (2004). Lane change warning design guidelines. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 2237-2241.
3. Young, S.K. (1996). Collision avoidance system performance specification for lane change, merging and backing: Phase I results and future plans. *Peer Review of the National Highway Traffic Safety Administration Program Workshop Proceedings*. Washington, DC: ITS America.
4. Lee, S.E., Olsen, E.C.B., and Wierwille, W.W. (2004). *A comprehensive examination of naturalistic lane-changes* (DOT HS 809 702). Washington, DC: National Highway Traffic Safety Administration.
5. Talmadge, S., Chu, R., Eberhard, C., Jordan, K., and Moffa, P. (2000). *Development of performance specifications for collision avoidance systems for lane change crashes* (DOT HS 809 414). Washington, DC: National Highway Traffic Safety Administration.
6. Kiefer, R., LeBlanc, D., Palmer, M. Salinger, J., Deering, R. and Shulman, M. (1999). *Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems* (Final Report DOT HT 808 964). Washington, DC: National Highway Traffic Safety Administration.

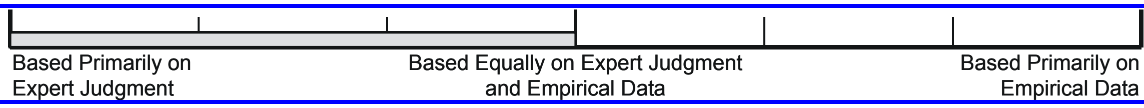
Design of CCWs for LCW Systems

Introduction

The design of CCWs describes the broad functional requirements of the CCWs for LCW systems as they relate to how drivers experience and interact with the system. The 1996 COMSIS Guidelines provide recommendations about presentation conditions, display modality, and location that are specific to CCWs (Reference 1). Most of the information from the 1996 COMSIS Guidelines is still applicable because there has been relatively little research on LCW systems since then.

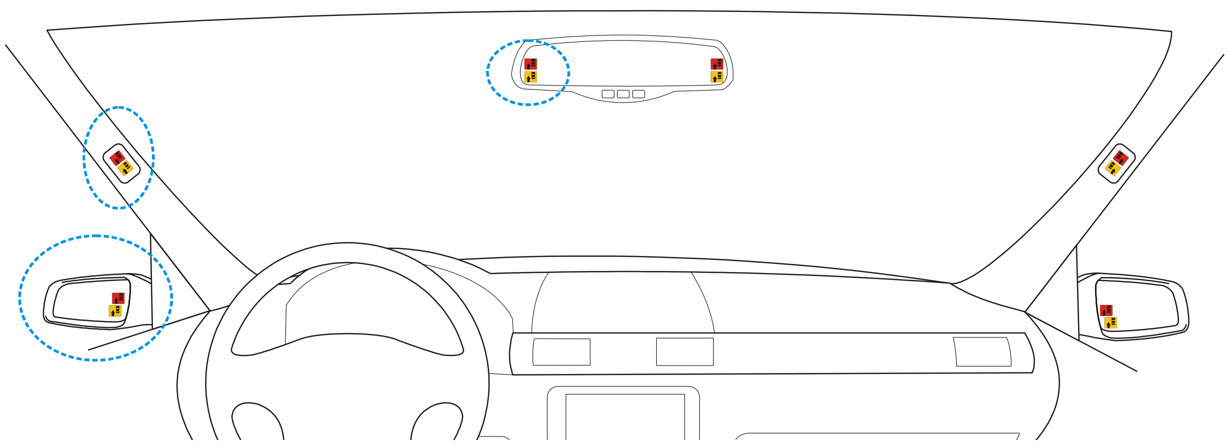
Design Guidelines

- The CCW should consist of an easily perceived, visual-only display that is not highly intrusive, (e.g., it should not flash).
- CCW detection zone and crash situation coverage should be the same as with the ICW.
- Higher false-alarm rates than for other types of CWS devices (e.g., once per week for FCW devices) are likely to be acceptable, but they still should be minimized.



Potential locations for LCW system visual displays

The figure below shows potential display locations for CCW and ICW visual displays. Left-side display locations are circled by the blue dashed line.



Discussion

Unlike recommendations for FCW systems, the use of CCWs is strongly recommended in LCW systems because they can augment driver situation awareness and provide information that aids decision-making well in advance of potential lane-change conflicts.

Display Modality: The CCW should consist solely of a visual display because auditory and haptic CCWs are highly intrusive, which makes them likely to annoy drivers since they would occur relatively frequently (Reference 1-4). Similarly, although the CCW should be easily visible (see guidelines on pages 4-8, 4-10, and 8-6), it should also be clearly distinguishable from the visual ICW.

Detection Zone: The CCW detection zone and crash situation coverage should be the same as with the ICW in order to help drivers develop and maintain a consistent mental model (Reference 2). The only difference between CCW and ICW conditions is that the ICW should be presented when the system detects the driver's intent to change lanes.

False Alarms: CCW false alarms should be minimized. However, false alarm rates that are higher than once per week (the recommendation for LCW system ICWs and warnings for other CWSs) are likely to be acceptable. This is because the recommended visual-only display (see the guideline on page 8-2) is unobtrusive and peripheral to the normal field of view. In particular, the CCW is less likely to be noticed regularly by drivers unless they are actively seeking that information. Also, the system investigated in Reference 2 had very high false-alarm rates (42 per hour for both ICW and CCW combined) and drivers generally reported that this level was acceptable and that it did not lead to increased annoyance.

Design Issues

None.

Cross References

How to Prevent False or Nuisance Warnings, 2-10
Desired Characteristics of Visual CCWs, 4-8
General Characteristics of Visual ICWs and CCWs, 4-10
Design of ICWs for LCW Systems, 8-2
Design of Visual, Auditory, and Haptic Warnings for LCW Systems, 8-6

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Talmadge, S., Chu, R., Eberhard, C., Jordan, K., and Moffa, P. (2000). *Development of performance specifications for collision avoidance systems for lane change crashes* (DOT HS 809 414). Washington, DC: National Highway Traffic Safety Administration.
3. Olsen, E. C. B. (2004). Lane change warning design guidelines. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting*, 2237-2241.
4. Young, S. K. (1996). Collision avoidance system performance specification for lane change, merging and backing: Phase I results and future plans. *Peer Review of the National Highway Traffic Safety Administration Program Workshop Proceedings*. Washington, DC: ITS America.

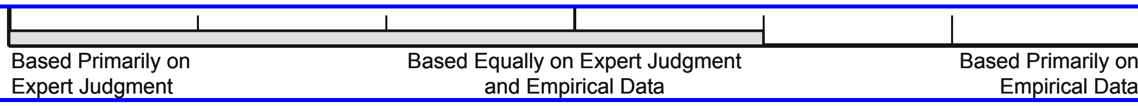
Design of Visual, Auditory, and Haptic Warnings for LCW Systems

Introduction

The design of visual, auditory, and haptic warnings refers to the recommended display characteristics for LCW systems. The 1996 COMSIS Guidelines provide general information about the location and characteristics of the visual warning and brief recommendations for auditory and haptic warnings (Reference 1). The current guidelines provide some additional information about these topics based on the limited amount of research conducted on LCW systems since the COMSIS work.

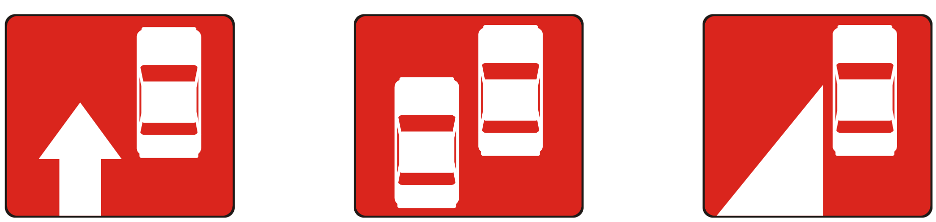
Design Guidelines

- The visual ICW should consist of a red icon/symbol flashing at 4 Hz, while the visual CCW should consist of a static yellow/amber icon/symbol located adjacent to the ICW.
- The visual display should consist of separate displays located on or next to both the side-view mirrors and the rear-view mirror.
- The recommended auditory ICW alert is a “long horn honk” auditory icon or another urgent-sounding alert that is clearly distinguishable from other in-vehicle auditory alerts.
- The auditory alert should emanate from a speaker located on the same side as the hazard and be presented at around 75 dB.



Recommended ICW icons for visual LCW system displays

The figure below shows three icon designs that received high ratings for blind spot and lane change warning icons.



Adapted from References 2 and 3

Discussion

References 2 and 3 identify three visual symbols/icons as being effective in conveying the urgency, location, and meaning of the visual warning in addition to having high user-preference ratings (see figure on previous page). In addition, References 2 and 3 provide information about additional icons/symbols that are also acceptable. Reference 4 used a generic red hazard triangle symbol for both the ICW and CCW and participants appeared to have no trouble identifying the meaning of the warning. This suggests that the display symbol/icon is not a critical design aspect since the meaning of the symbol is adequately implied by the display locations.

Reference 4 used identical visual displays for both ICWs and CCWs with the exception that the ICW flashed while the CCW was static. Eight out of ten drivers in this study reported that the ICW display was noticeable and attracted attention, but did not negatively affect their driving performance. While this approach of using the same visual alert for both ICW and CCW may be acceptable, using visual warnings that differ in color (i.e., red ICW and yellow/amber CCW) and have different but adjacent locations should increase the conspicuity of the ICW. Also, using warnings that are identical except that the ICW flashes runs a slight risk that drivers will confuse the warning types during a quick glance near the display.

Two studies report no practical driver performance (Reference 4) or warning detection (Reference 2) differences between different display locations configurations (side only versus rear-view only versus both). Reference 4 recommends using both locations because: 1) it is the configuration that is most preferred by drivers and 2) it best accommodates a wide variety of observed driver glance behavior.

The A-pillar may also provide an acceptable display location, however, no data are available to support conclusions about the effectiveness of this location. Two drawbacks of using this location are that it would likely require an additional glance to the A-pillar for drivers to obtain or confirm the LCW system information and it may be more obtrusive and consequently more annoying for CCWs because it is closer to the forward field of view.

Research conducted with heavy vehicles indicates that a “long horn honk” auditory icon is more effective than a conventional, urgent-sounding simple tone display for warning drivers about lane-change conflicts if it is presented in conjunction with a visual display (Reference 5). Another relevant finding from this study was that the meaning of the auditory icon was recognized by almost all drivers, whereas drivers recognized the meaning of the simple tone auditory warning no better than 50 percent of the time.

Haptic warning signals may also warrant consideration in place of an auditory ICW, especially if auditory ICWs are used in other systems (e.g., FCW systems) and could potentially lead to confusion. In particular, haptic warnings in the form of steering wheel torque away from the destination lane (i.e., a single triangle wave at 2.0 Nm of force with a half-period 0.5 sec) have been shown to be effective in prompting drivers to cancel lane changes with conflicting vehicles present (References 6 and 7). However, only a limited amount of research has been conducted on haptic warnings, and many safety-related issues are still unresolved, such as long-term driver acceptance and how haptic feedback affects driver performance under different roadway conditions (e.g., icy roads).

Design Issues

False-alarm rates for ICWs should be considered when determining ICW characteristics. In particular, with early systems, ICW false-alarm rates could be higher than desirable (e.g., more than once per week) and it may be necessary to consider using an ICW that has less obtrusive characteristics to limit driver annoyance. In this case, a visual-only ICW may be appropriate.

Cross References

Determining the Appropriate Display Type for Haptic ICWs, 5-4
Design of ICWs for LCW Systems, 8-2
Design of CCWs for LCW Systems, 8-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Campbell, J.L., Hooey, B.H., Carney, C., Hanowski, R.J., Gore, B.F., Kantowitz, B.H., et al. (1996). *Investigation of alternative displays for side collision avoidance systems* (Final Report). Seattle, WA: Battelle Seattle Research Center.
3. Sayer, T.B. (2002). The development and evaluation of icons for side obstacle warning systems. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, 1794-1798.
4. Talmadge, S., Chu, R., Eberhard, C., Jordan, K., and Moffa, P. (2000). *Development of performance specifications for collision avoidance systems for lane change crashes* (DOT HS 809 414). Washington, DC: National Highway Traffic Safety Administration.
5. Belz, S.M., Robinson, G.S., and Casali, J.G. (1999). A New Class of Auditory Warning Signals for Complex Systems: Auditory Icons. *Human Factors*, 41(4), 608-618.
6. Farber, B., Naab, K., and Schumann, J. (1991). *Evaluation of prototype implementation in terms of handling aspects of driving tasks* (Deliverable Report DRIVE V1041/GIDS CON3). Haren, The Netherlands: Traffic Research Institute, University of Groningen.
7. Schumann, J., Godthelp, H., Farber, B., and Wontorra, H. (1993). Breaking up open-loop support for the driver’s lateral control task. In A. G. Gale et al. (Eds.) *Vision in Vehicles IV* (pp. 321-332). London: Taylor and Francis.

CHAPTER 9. ROAD DEPARTURE WARNING SYSTEMS

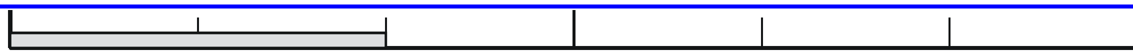
Design of Lane Drift Warning ICWs for RDCW Systems

Introduction

The design of ICWs describes the broad functional requirements of ICWs for the LDW component of RDCW systems as they relate to how drivers experience and interact with the system. Note that this topic was not covered in the 1996 COMSIS Guidelines (Reference 1), and most of the information provided in this guideline comes from the 2006 Field Operational Test (FOT) described in Reference 2.

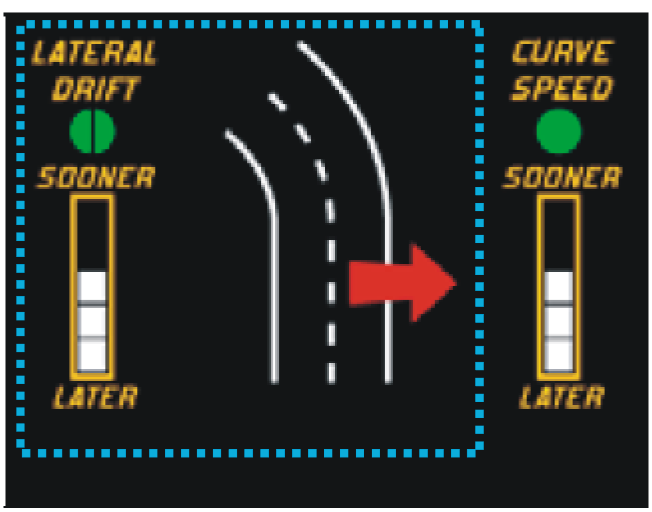
Design Guidelines

- The ICW should consist of a multimodal display consisting primarily of a conspicuous auditory signal emanating from the direction of the lane drift, supplemented by a concurrent visual display.
- The ICW should be presented when the system detects that: 1) the vehicle has crossed a *solid*-line boundary without having the turn signal activated, *or* 2) if vehicle crosses a dashed-line boundary and other vehicles or objects are detected in the relevant detection zone adjacent to the driver's vehicle.
- A combined ICW and CCW false-alarm rate of approximately 1.5 per 100 miles appears to be acceptable to drivers.
- LDW system availability should be clearly displayed so that drivers can easily determine whether or not LDW capabilities are available.



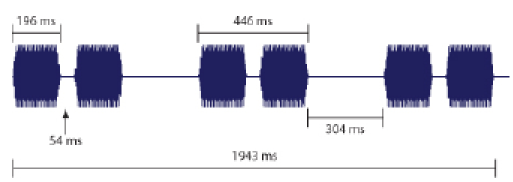
The figure below depicts the visual and auditory components of the LDW ICW display used in Reference 2. The full visual display included both the LDW and CSW information and the relevant LDW elements are shown within the blue dashed border. The red arrow represents the LDW ICW symbol, the green half circles indicate the system availability status for the left and right sides of the vehicle, and the "sooner/later" meter displays the system sensitivity settings.

Visual Display



Auditory Display

Three pairs of "beep-beep" tones



Intensity = ambient noise level + 15 dBA (3)

(The radio volume was automatically reduced if it was in use and ambient noise levels were high.)

Adapted from Reference 2

Discussion

Display Modality: The FOT implemented in Reference 2 used a primary auditory ICW, supplemented with a visual LHDD. The visual display used in Reference 2 did not appear to be as effective as the auditory warning in communicating alert information. In particular, drivers reported somewhat greater uncertainty about the nature of the warning (e.g., LDW or CSW) with the visual display than with the auditory display. Also, more drivers reported not noticing the visual warnings than the auditory warnings and, in subsequent focus group interviews, some test drivers indicated that while they would have liked to use the visual display to get feedback about the type of warning they received, the information was typically extinguished by the time they tried to view it. Nevertheless, in post-field-test questionnaires conducted in Reference 2, most drivers reported that the visual display was in a convenient location, the graphics were the right size, and the display was easy to see and understand. Note also that a visual display located closer to the driver's expected line of sight is likely to be more noticeable (e.g., HHDD), and separating the left and right side visual displays may facilitate warning interpretation. However, there is no RDCW system data currently available to support this assertion.

The auditory warning was very likely to be perceived as attention-getting by drivers. Drivers also reported that it was easy to hear, not annoying, and that they knew what the warning meant when it occurred. Several drivers, however, also reported difficulty in determining from which side the auditory warning was emanating.

If a haptic warning is used as part of the LDW system CCW, then it should not be used as part of the ICW in order to help drivers distinguish between the two types of warnings.

Warning Conditions: For vehicles crossing dashed-line boundaries, ICWs should be presented once the driver's Available Maneuvering Room (AMR) relative to potential hazards drops below a minimum level. Reference 2 calculated the AMR for a zone extending forward the equivalent of 3.5 seconds of headway on both sides of the vehicle. Parameters that were included in the calculation of the AMR included: 1) road type, which was used to set a default threshold, 2) driver's selection of LDW sensitivity, 3) current radar observations of distances to stationary or moving objects in the adjacent lane or on the roadway edge, and 4) a geo-coded memory of objects observed alongside the travel lane on previous traversals of the current road segment by that driver.

False Alarms: The recommended false-alarm rate represents an estimated false-alarm rate that drivers appear to find acceptable. In particular, approximately 17 percent of the total LDW system ICW and CCW alerts recorded in Reference 2 were estimated to be false alarms. Based on a median total alert rate of 9 alerts per 100 miles, approximately 1.5 alerts per 100 miles could be expected to be false alarms. Overall, drivers reported that the perceived false-alarm rate was not excessive or particularly annoying, which leads to the extrapolation that a combined ICW and CCW false-alarm rate of 1.5 false alarms per 100 miles appears to be acceptable.

Note that as part of the overall strategy for addressing false alarms, Reference 2 used several criteria for suppressing alarms. These included: 1) if the vehicle's speed is less than 25 mph, 2) if the turn signal had been applied within the past 5 seconds, 3) if the brake had been applied within the past 5 seconds, 4) if travel was on a neighborhood street or similar, low-speed and low-volume road, 5) if confidence of lane tracking was inadequate for issuing an alert, and 6) at night with the wipers activated (i.e., rain at night because it leads to poor lane tracking performance).

Drivers should be given some control over sensitivity settings. Many drivers in Reference 2 changed the system settings based on their driving style and based on situational factors such as traffic and weather conditions and alertness or fatigue levels. Also, most drivers reported that it was easy to understand how the sensitivity settings affected LDW alerts. The provision of an on-off switch is also recommended to address potential situations that could trigger high false-alarm rates (e.g., work zones or bad weather), despite the fact that most drivers reported that they would not have used an on-off switch if it had been available.

Availability Indicator: Until the technology matures, LDW system availability may be low and variable across driving situations. At this point, the effect of low availability on driver factors, such as system trust and driver acceptance of the technology, is unclear. If availability changes frequently (e.g., more than four times per hour), then an auditory signal that accompanies the change in availability status is not recommended because it is likely to annoy drivers (Reference 3). Apart from this, it is unknown whether providing drivers with an auditory indication availability status change has any positive or negative effects. While it is prudent to provide auditory feedback regarding the status of systems that drivers rely upon (e.g. Reference 1), it appears that neither driver performance nor driver perception of system usefulness were negatively affected by not providing this information in Reference 2.

Design Issues

See discussion of Design Issues in guideline on page 9-4.

Cross References

Design of CCWs for LDW Systems, 9-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, J., et al. (2006). *Road Departure Crash Warning Field Operational Test*. Washington, DC: National Highway Traffic Safety Administration.
3. Lerner, N.D., Dekker, D.K., Steinberg, G. V., and Huey, R. W. (1996). *Inappropriate alarm rates and driver annoyance* (DOT HS 808 533). Washington, DC: National Highway Traffic Safety Administration, Office of Crash Avoidance Research.

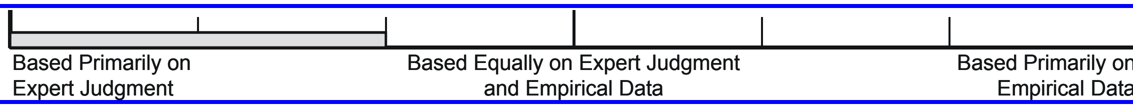
Design of Lane Drift Warning CCWs for RDCW Systems

Introduction

The design of ICWs describes the broad functional requirements of CCWs for the LDW component of RDCW systems as they relate to how drivers experience and interact with the system. Note that this topic was not covered in the 1996 COMSIS Guidelines (Reference 1), and most of the information provided in this guideline comes from the 2006 FOT described in Reference 2.

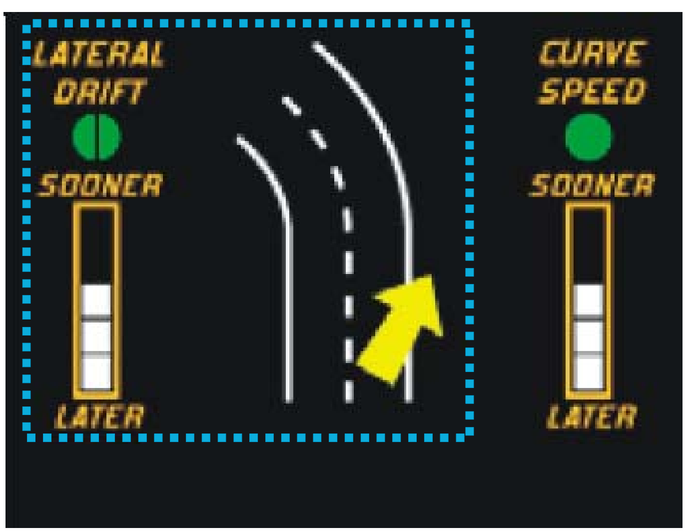
Design Guidelines

- The CCW should consist of a multimodal display consisting primarily of a haptic signal presented from the seat pan that is lateralized in direction of the lane drift, supplemented by a concurrent visual display.
- The ICW should be presented when the system detects that: 1) the vehicle has crossed a dashed-lane boundary without having the turn signal activated, and 2) when no other objects are detected in the relevant detection zone adjacent to the driver's vehicle.
- A combined ICW and CCW false-alarm rate of approximately 1.5 per 100 miles appears to be acceptable to drivers.
- LDW system availability should be clearly displayed so that drivers can easily determine whether or not LDW capabilities are available.



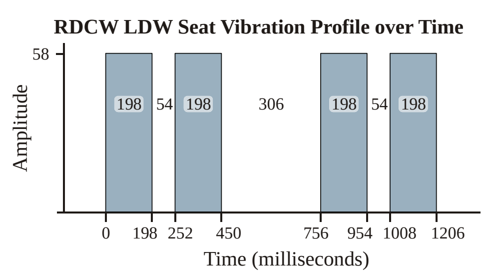
The figure below depicts the visual and haptic components of the LDW CCW display used in Reference 2. The full visual display included both the LDW and CSW information and the relevant LDW elements are shown within the blue dashed border. The yellow arrow represents the LDW ICW symbol, the green half-circles indicate the system availability status for the left and right sides of the vehicle, and the "sooner/later" meter displays the system sensitivity settings.

Visual Display



Haptic Display

(Presented by two lateral motors on each side of the seat pan)



Adapted from Reference 2

Discussion

Display Modality: The FOT implemented in Reference 2 used a primary haptic CCW, supplemented with a visual LHHD that was the same as the visual ICW display, except that the warning indicator arrow was yellow rather than red and it had a different orientation. Similar to the LDW ICW, the CCW visual display used in Reference 2 did not appear to be as effective as the haptic warning in communicating alert information. In particular, drivers reported somewhat greater uncertainty about the nature of the warning (e.g., LDW or CSW) with the visual display than with the haptic display. Also, more drivers reported not noticing the visual warnings than the haptic warnings.

Reference 2 used a haptic CCW that was designed to mimic the vibration encountered by crossing a rumble strip, except that it was localized to the side of the seat pan in the direction of the vehicle drift. The results presented in Reference 2 indicate that the haptic warning was very likely to be perceived as attention-getting by most drivers. They also reported that the haptic warnings were not annoying, and that they knew what the warning meant when it occurred. Most drivers also reported that they could easily recognize under which leg the seat vibration was coming from. In fact, localizing the haptic warning appeared to be easier than localizing the auditory ICW for many drivers. From a safety aspect, the haptic vibration also appeared to promote increased use of turn signals because changing lanes without signaling would initiate the haptic CCW.

Warning Conditions: The system should determine the presence of hazards adjacent to the subject vehicle—based on AMR—the same way as for CCWs and ICWs. If no potential hazard is identified as the subject vehicle crosses a dashed-line boundary, than a CCW should be presented.

False Alarms: The recommended false-alarm rate represents an estimated false-alarm rate that drivers appear to find acceptable. In particular, approximately 17 percent of the total LDW system ICW and CCW alerts recorded in Reference 2 were estimated to be false alarms. Based on a median total alert rate of 9 alerts per 100 miles, approximately 1.5 alerts per 100 miles could be expected to be false alarms. Overall, drivers reported that the perceived false-alarm rate was not excessive or particularly annoying, which leads to the extrapolation that a combined ICW and CCW false-alarm rate of 1.5 false alarms per 100 miles appears to be acceptable.

The CCWs should be suppressed under the same conditions as ICWs (see False Alarms section in guideline on page 9-2) and they should use the same sensitivity settings.

Availability Indicator: System availability should be addressed in the same manner as described in the guideline on page 9-2. With the LDW system, availability affects both ICWs and CCWs in the same manner, and they do not need to be differentiated along these lines.

Design Issues

One aspect that potentially complicates proper driver understanding of how the system functions is that the LDW system in Reference 2 was suppressed under several conditions. In particular, system function was suppressed: 1) if the vehicle speed was less than 25 mph, 2) if the turn signal had been applied within the past 5 seconds, 3) if the brake had been applied within the past 5 seconds, 4) if travel was on a neighborhood street or similar, low-speed and low-volume road, 5) if confidence of lane tracking was inadequate for issuing an alert, and 6) at night with the wipers activated.

One unresolved question at this point is whether or not drivers' understanding of how the system operates (their mental model of the system) is impaired by the fact that system operation is disabled in a significant number of situations. This has implication for driver trust in the system and the degree to which they will rely on the information it provides. The data from Reference 2 indicate that only a small percentage of drivers reported the strongest agreement levels with the statement "I relied on the LDW system," which suggests that overall reliance on the system was not high. However, reliance was also reported to be low with the CSW system that had fewer limitations regarding when it was enabled, which suggests that other factors (e.g., unfamiliarity with the technology) may have impacted reported reliability more than the understanding of when the system was suppressed.

One implication of this is that if these systems are expected to become widespread, it may be necessary to provide some standardization of the conditions under which system operation is suppressed to ensure that drivers do not make any unsafe assumptions about when the system is operational when traveling in a new or unfamiliar vehicle.

Cross References

Design of ICWs for LDW Systems, 9-2

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, et al. (2006). *Road Departure Crash Warning Field Operational Test*. Washington, DC: National Highway Traffic Safety Administration.

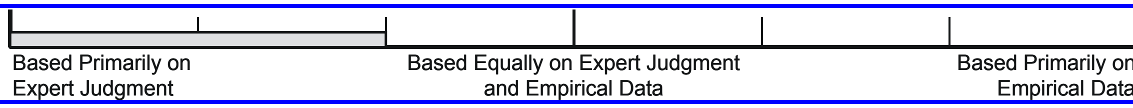
Design of Curve Speed Warning ICWs for RDCW Systems

Introduction

The design of ICWs describes the broad functional requirements of ICWs for the CSW component of RDCW systems as they relate to how drivers experience and interact with the system. Note that this topic was not covered in the 1996 COMSIS Guidelines (Reference 1), and most of the information provided in this guideline comes from the 2006 FOT described in Reference 2.

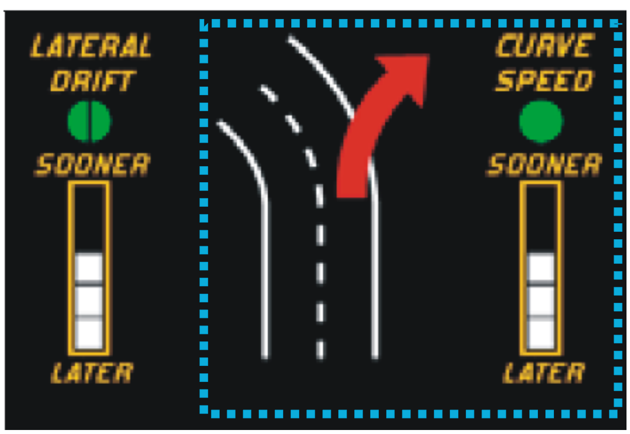
Design Guidelines

- The ICW should consist of a multimodal display consisting primarily of a conspicuous and brief auditory speech signal consisting of the words "Curve! Curve!" supplemented by a concurrent visual display.
- The ICW should be presented when CCW conditions persist and if the vehicle dynamics do not indicate that the driver has initiated a response to the initial CCW.
- A rough estimate is that false-alarm rates higher than 0.5-1.0 per 100 miles may lead to driver annoyance.
- CSW system availability should be clearly displayed so that drivers can easily determine whether or not CSW capabilities are available.



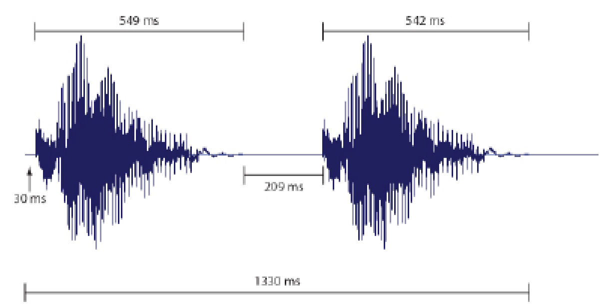
The figure below depicts the visual and auditory components of the CSW ICW display used in Reference 2. The full visual display included both the LDW and CSW information and the relevant CSW elements are shown within the blue dashed border. The red arrow represents the CSW ICW symbol, the green circle indicates the system availability status, and the "sooner/later" meter displays the system sensitivity settings.

Visual Display



Auditory Display

The speech message: "Curve! Curve!"



Intensity = ambient noise level + 15 dBA (3)

(The radio volume was automatically reduced if it was in use and ambient noise levels were high.)

Adapted from Reference 2

Discussion

Display Modality: The FOT implemented in Reference 2 used a primary auditory ICW, supplemented with a visual LHHD. The results from driver surveys indicate that the visual display did not appear to be as effective as the auditory warning in communicating alert information. In particular, drivers reported somewhat greater uncertainty about the nature of the warning (e.g., LDW or CSW) with the visual display than with the auditory display, and they also tended to be less certain about what to do following the visual warning than the auditory warning. Also, more drivers reported not noticing the visual warnings than the auditory warnings. Some drivers also reported some uncertainty regarding being able to distinguish between visual ICW and CCW symbols. However, in post-field-test questionnaires conducted in Reference 2, most drivers reported that the visual display was easy to see and that the graphics were the right size. Also, most drivers were not confused by the fact that the curve on the CSW display always pointed to the left, regardless of the direction of the curve ahead.

The auditory speech warning ("Curve! Curve!") was very likely to be perceived as attention-getting by drivers, and drivers also reported that it was easy to hear and that they knew what the warning meant when it occurred.

If a haptic warning is used as part of the LDW system CCW, then it should not be used as part of the ICW in order to help drivers distinguish between the two types of warnings.

Warning Conditions: TBD

The ICW presentation criteria should be based on the same conditions as the CCW. If the system detects that the CCW conditions persist and the vehicle dynamics do not indicate that the driver has initiated a response to the initial CCW, then the ICW should be presented. Reference 2 implemented a minimum 1.3 second delay between the CCW and ICW. In practice, most ICWs occurred between 1.4 or 1.5 seconds after the initial CCW. Although, ICWs typically follow CCWs, under fast-emerging high-threat situations, just the ICW may be presented.

False Alarms: The recommended false-alarm rate is estimated from several data elements in Reference 2. Overall, false-alarm rates in this study were around 57 percent for the CSW system, with 25 percent of all CCW and ICW alarms triggered by adjacent curves located on road branches that were not traversed by the driver and 32 percent triggered by system errors/improper functioning. In general, this level of false alarms was rated as not annoying by most drivers.

The specific false-alarm range presented in this guideline was derived from post-FOT driver interviews in which drivers reviewed video footage of a sub-sample of CSW alerts that they previously experienced. Drivers rated approximately 50 percent of ICWs reviewed as being "not at all useful." This 50-percent value multiplied by the median ICW rate of 1.6 per 100 miles driven yields an estimated 0.8 ICWs per 100 miles that are estimated to be "not at all useful," which forms the basis for the guideline recommendation. Note that it is important that the recommended false alarm rate be interpreted as a crude ballpark estimate, because there are, currently, only limited and indirect data indicating that this range would actually yield an acceptable level of false alarms.

It is also recommended that drivers be given some control over sensitivity settings. Many drivers in Reference 2 changed the system settings based on their driving style, although most adjustment activity abated after the first week of use of the system. Also, most drivers reported that it was easy to understand how the sensitivity settings affected LDW alerts. The provision of an on-off switch is also recommended to address potential situations that could trigger high false alarm rates (e.g., work zones or bad weather), despite the fact that most drivers reported that they would not have used an on-off switch if it had been available.

Availability Indicator: It is recommended that drivers be provided with an availability status indicator for the CSW system. Although availability was generally high with this system, most drivers reported that the availability indicator provided helped them understand and use the CSW system.

Design Issues

Reference 2 found that a disproportionate number of alerts occur on exit ramps or other transitional roadway segments. In particular, 53 percent of all events were related to transitional roadway segments (approximately one half of those are false alarms), while these segments represented only 14 percent of the total roadway driven. Also, drivers' lateral acceleration on curves on ramps tended to be significantly higher than on other types of curves. Adequately addressing system performance related to these transitional elements will be important for reducing false alarms and promoting the usefulness of CSW systems.

Cross References

Design of CCWs for LDW Systems, 9-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.

2. LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, et al. (2006). *Road Departure Crash Warning Field Operational Test*. Washington, DC: National Highway Traffic Safety Administration.

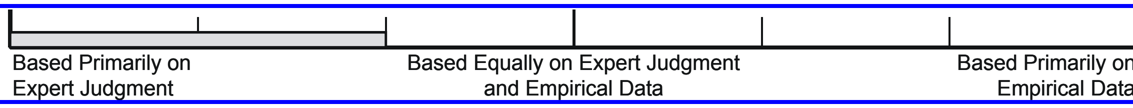
Design of Curve Speed Warning CCWs for RDCW Systems

Introduction

The design of CCWs describes the broad functional requirements of CCWs for the CSW component of RDCW systems as they relate to how drivers experience and interact with the system. Note that this topic was not covered in the 1996 COMSIS Guidelines (Reference 1), and most of the information provided in this guideline comes from the 2006 FOT described in Reference 2.

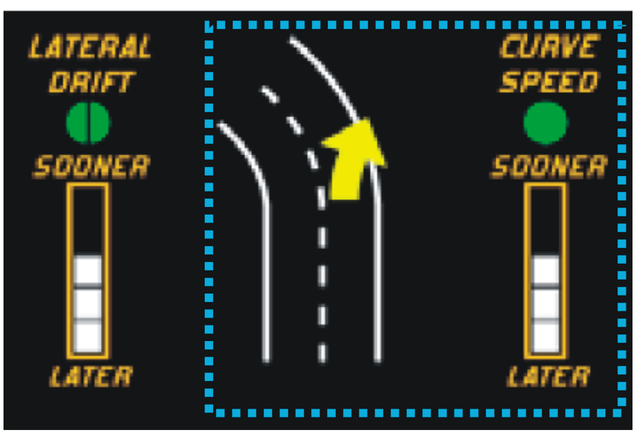
Design Guidelines

- The CCW should consist of a multimodal display consisting primarily of a haptic warning presented on the forward section of the seat pan, supplemented by a concurrent visual display.
- The CCW should be presented when the system detects that: 1) the most likely/predicted vehicle path will be along a curve, *and* 2) the vehicle's speed profile (considering other factors such as driver response time) indicates that the vehicle lateral acceleration will exceed 0.25g at some point along the curve.
- A rough estimate is that false alarm rates higher than 1.0-1.5 per 100 miles may lead to driver annoyance.
- CSW system availability should be clearly displayed so that drivers can easily determine whether or not CSW capabilities are available.

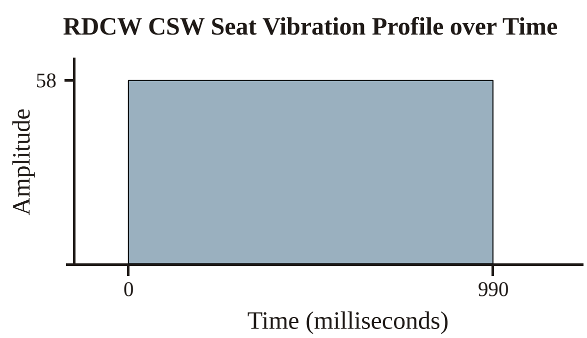


The figure below depicts the visual and auditory components of the CSW CCW display used in Reference 2. The full visual display included both the LDW and CSW information and the relevant CSW elements are shown within the blue dashed border. The yellow arrow represents the CSW CCW symbol, the green circle indicates the system availability status, and the "sooner/later" meter displays the system sensitivity settings.

Visual Display



Haptic Display



Adapted from Reference 2

Discussion

Display Modality: The FOT implemented in Reference 2 used a primary haptic CCW, supplemented with a visual LHHD. The visual display used in Reference 2 did not appear to be as effective as the haptic warning in communicating alert information. In particular, drivers reported somewhat greater uncertainty about the nature of the warning (e.g., LDW or CSW) the visual display than with the haptic display, and they also tended to be less certain about what to do following with the visual warning than the haptic warning. Also, more drivers reported not noticing the visual warnings than the haptic warnings. Some drivers also reported some uncertainty regarding being able to distinguish between visual ICW and CCW symbols. However, in post-Field-Test questionnaires conducted in Reference 2, most drivers reported that the visual display was easy to see and that the graphics were the right size. Note also that a visual display located closer to the drivers expected line of sight is likely to be more noticeable (e.g., a HHDD). However, there is no RDCW system data currently available to support this assertion.

Reference 2 used a haptic CCW that provided a sustained vibration from two motors located at the front of the seat pan. The results presented in Reference 2 indicate that the haptic warning was very likely to be perceived as attention-getting by most drivers. They also reported that the haptic warnings were not annoying, and that they knew what the warning meant when it occurred. Most drivers also reported that they could easily recognize that the vibration was emanating from the front of the seat pan.

Warning Conditions: The CSW system should provide warnings to help drivers avoid entering or driving through curves at speeds that are too fast for safety. The CSW system evaluated in Reference 2 took into account performance factors, such as driver response time, to provide drivers with sufficient time to slow the vehicle if it was on course to surpass 0.25g in lateral acceleration. The 0.25g threshold was a baseline criteria that was modified based on factors such as roadway type and selected sensitivity setting. Also, warnings were suppressed if the vehicle's speed was less than 18 mph.

To the extent possible, the system should be able to predict when a driver that is passing a roadway branch (e.g., exit ramp) will not enter that branch to avoid presenting unnecessary false alarms.

False Alarms: The recommended false alarm rate is estimated from several data elements in Reference 2. Overall, false alarm rates in this study were around 57 percent for the CSW system, with 25 percent of all CCW and ICW alarms triggered by adjacent curves located on road branches that were not traversed by the driver and 32 percent triggered by system errors/improper functioning. In general, this level of false alarms was rated as not annoying by most drivers.

The specific false alarm range presented in this guideline was derived from post-FOT driver interviews in which drivers reviewed video footage of a sub-sample of CSW alerts that they previously experienced. Drivers rated approximately 33 percent of ICWs reviewed as being "not at all useful." This 33-percent value multiplied by the median ICW rate of 3.9 per 100 miles driven yields an estimated 1.3 ICWs per 100 miles that are estimated to be "not at all useful," which forms the basis for guideline recommendation. Note that it is important that the recommended false alarm rate be interpreted as a crude ballpark estimate, because there are, currently, only limited and indirect data indicating that this range would actually yield an acceptable level of false alarms.

It, also, is recommended that drivers be given some control over sensitivity settings. Many drivers in Reference 2 changed the system settings based on their driving style, although most adjustment activity abated after the first week of use of the system. Also, most drivers reported that it was easy to understand how the sensitivity settings affected CSW alerts. The provision of an on-off switch is also recommended to address potential situations that could trigger high false alarm rates (e.g., work zones or bad weather), despite the fact that most drivers reported that they would not have used an on-off switch if it had been available.

Availability Indicator: It is recommended that drivers be provided with an availability status indicator for the CSW system. Although availability was generally high with this system, most drivers reported that the availability indicator provided helped them understand and use the CSW system.

Design Issues

None.

Cross References

Design of CCWs for LDW Systems, 9-4

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. LeBlanc, D., Sayer, J., Winkler, C., Ervin, R., Bogard, S., Devonshire, et al. (2006). *Road Departure Crash Warning Field Operational Test.* Washington, DC: National Highway Traffic Safety Administration.

CHAPTER 10. APPLICATION TO HEAVY TRUCKS AND BUSES

Large-Vehicle CWS Display and Enunciator Location

Introduction

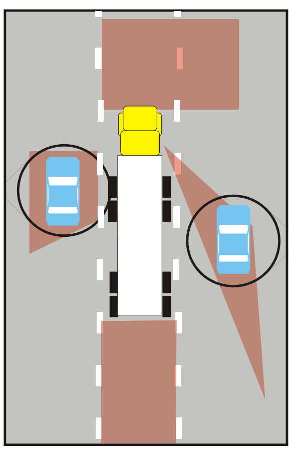
Large vehicle CWS Display and Enunciator location refers to the positioning of warning signal visual displays, auditory enunciators, and haptic display mechanisms within the heavy truck and transit bus driver environment. These guidelines integrate guidance from the 1996 COMSIS Guidelines (Reference 1) and more recent analyses of large vehicle operations.

Design Guidelines

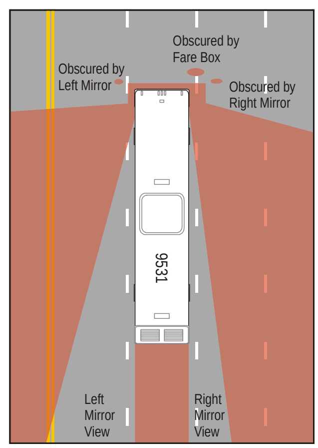
- Display location must be compatible with trained and appropriate visual scanning behaviors.
- LCW primary displays should be closely aligned with the driver's line of sight to side-view mirrors.
- Avoid locating visual collision warnings on the instrument panel of large vehicles.
- Transit bus CWS display location should consider passenger viewing as well as driver visibility.

Based Primarily on Expert Judgment	Based Equally on Expert Judgment and Empirical Data	Based Primarily on Empirical Data

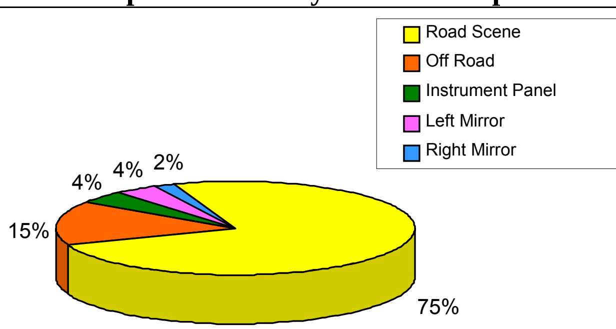
Large vehicle drivers typically allocate much of their visual resources to scanning the forward roadway and viewing their mirrors to maintain awareness of lateral hazards. The two upper frames in the figure below depict typical blind spot configurations for heavy trucks (adapted from Reference 2) and transit buses (adapted from Reference 3). The two lower frames of the figure below depict results of on-road studies of large vehicle driver glance times, providing drivers' general allocation of visual resources in heavy trucks (Reference 4) and transit buses (Reference 5).



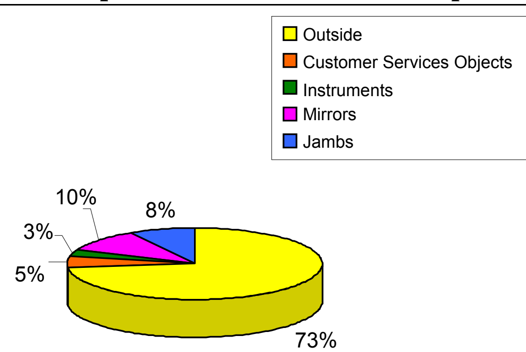
A. Depiction of heavy truck blind spots.



B. Depiction of transit bus blind spots.



C. Heavy truck driver allocation of visual resources.



D. Transit bus driver allocation of visual resources.

Discussion

Overall visual allocation and individual glance times of heavy-truck drivers (Reference 4) and transit bus drivers (Reference 5) indicate that over 70 percent of glance times during driving are directed towards the forward road scene for glances that range from 0.5 to 5 seconds and more. These same references also indicate that large-vehicle drivers allocate approximately 10 percent of glance times to mirrors for glances that are typically less than 1 second during driving. Thus, FCW visual displays should be mounted in or near the forward line of sight and LCW and Side Collision Warning (SCW) visual displays should be mounted in or near the side mirror line of sight. Reference 1 indicates that such displays should not be mounted more than 15 degrees vertically and 15 degrees horizontally from the driver's line of sight of the mirrors.

Driver glances to the instrument panel by large-vehicle drivers appear to be limited in both frequency and duration. The available data suggest that heavy-truck drivers allocate between 2 and 4 percent of their total visual glance time in looking at the instrument panel (Reference 4). Similar visual allocation levels are suggested by the available transit bus driving glance time data, where 3.2 percent of total glance time was estimated to be spent looking at the bus instrument panel (Reference 5). Although visual warning displays should not be located in instrument panels, this is an appropriate location for controls and status displays, especially if an auditory status warning is provided to orient the driver to the display.

Both Reference 6 and Reference 7 raise a concern regarding transit bus passenger reactions to collision warnings. However, these concerns were not supported by any driver comments regarding what seems to be a relatively conspicuous visual display in the integrated CWS pilot study reported in Reference 7. Reported transit bus driver ratings suggested that few passengers (rating of 2.4 on a 1-5 scale) commented on the display, but those that did generally provided a positive response (3.8 on a 1-5 scale).

Design Issues

HUDs have the potential to provide drivers with critical information while minimizing glance times away from the forward roadway scene. However, relatively high HUD display costs have limited commercial applications. The substantial costs associated with large vehicle crashes suggests that HUDs could provide a cost-effective option for locating CWS visual displays within the large vehicle driver's forward line of sight. Further consideration and evaluation of HUD display characteristics could be appropriate for future CWS display development efforts.

Cross References

How to Integrate Warning Systems, 2-2
How to Make Warnings Compatible with Driver Responses, 2-8

References for the Design Guideline

1. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
2. Transports Quebec. (2006). *Heavy vehicle blind spots, collision danger zones*. Retrieved April 6, 2006 from http://www.mtq.gouv.qc.ca/en/camionnage/lourds/campagne/index.asp
3. Thorpe, C., Duggins, D., McNeil, S., and Mertz C. (2002). *Side Collision Warning System (SCWS) Performance Specifications for a Transit Bus. Final Report*. Pittsburgh, PA: Carnegie Mellon University Robotics Institute.
4. Tijerina, L; Kiger, S.; Rockwell, T.; Tomow, C.; Kinateder, J.; and Kokkotos, F. (1995). *Heavy Vehicle Driver Workload Assessment. Task 6: Baseline Data Study* (DOT HS 808 467(6)). Washington DC: National Highway Traffic Safety Administration.
5. Gobel, M., Springer, J., and Scherff, J. (1998). Stress and strain of short haul bus drivers: Psychophysiology as a design oriented method for analysis. *Ergonomics, 41*(5), 563-580.
6. Reinach, S. and Everson, J. (2001b). The preliminary development of a driver-vehicle interface for a transit bus collision avoidance system. *Intelligent Transportation Society of America Eleventh Annual Meeting and Exposition*.
7. University of California (UC) PATH and Carnegie Mellon University Robotics Institute (CMURI). (2006). *Integrated Collision Warning System Final Evaluation Report*. Washington, DC: Federal Transit Administration.

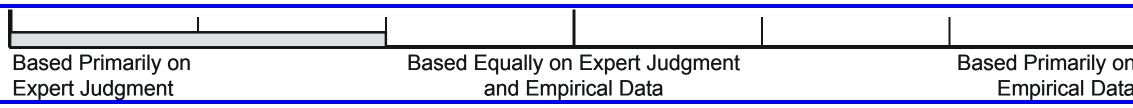
Large Vehicle CWS Warning Modality

Introduction

Large-vehicle warning modality refers to the recommended sensory modalities for large vehicle CWS informational displays and alarms.

Design Guidelines

- Exclusively visual ICWs should be avoided for FCWs and SCWs.
- Combined auditory and visual warnings generally provide the best response to ICWs.
- Vibration warnings should be avoided if they will be masked by high vehicle vibration levels.
- Avoid control-based haptic warnings (e.g., brake pulse and steering wheel torque) if they will interfere with driver control of the vehicle.



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 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 can be used to alert the driver to the presence of more specific cautionary information.	An attention-demanding tone or auditory earcon can be used to immediately direct the driver's attention to an imminent hazard.
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.	Not recommended.	Evaluation of adequate driver comprehension and timely response would be required prior to implementation.
Multi-modal	A multi-modal auditory alert coupled with a visual icon or message is the most commonly recommended means of alerting and conveying CWS status information.	A multi-modal 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.

Discussion

The amount of required visual scanning between the forward road scene and side mirrors while driving large vehicles suggests that an exclusively visual ICW could be either visually distracting or not attended to by drivers. Following an analysis of transit bus CWS requirements, Reference 1 concluded that multi-modal CWS warnings would be required due to the presence of a high amount of mechanical (vibration) and ambient sound noise, in combination with the high visual-demands of the job. Reference 2 reported the development of a transit bus CWS visual/auditory warning display that included both "percussive" and "aggressive" auditory signals for the SCW system. Following implementation of exclusively visual warnings in a transit bus CWS pilot study, it was reported that "…operators were not always aware of some of the alerts that were given, particularly if they were busy or the displays were not in their direct line of sight at the time. This could be addressed by adding an audible alert to the current visual alert, but that is a controversial feature that is strongly opposed by some operators even though it is favored by other operators (Reference 3). Existing evidence supports the use of auditory signals for ICWs to ensure timely perception of the warning in all large vehicles. However, the nature of the auditory tone must take into account both the fluctuating ambient auditory setting in all large vehicles and the legitimate issue of not alarming or alerting transit bus passengers unnecessarily.

Reference 4 describes a study in which auditory warnings resulted in better brake response time than a dash-mounted visual display that was located out of the driver's direct field of view in a heavy truck driving simulator. Indeed, the visual display resulted in slower brake response time than no warning display at all. These researchers interpreted this latter finding as indicating that presenting collision avoidance information exclusively via a visual display could distract the driver and may result in longer response times than no collision warning at all. In this study, combined visual and auditory displays in FCW systems were found to be generally more effective than visual- or auditory-only displays. Auditory icons for LCW (long horn honk) were found to result in fewer lane merge collisions than a conventional, urgent-sounding auditory warning but only if presented in conjunction with a visual display. As noted earlier, the recent pilot test of the integrated transit bus CWS deviated from the prevailing guidance and their original warning design in implementing a system with exclusively visual warnings (Reference 3).

Transit CWS displays must be capable of being presented, attended to, and understood under high-vibration conditions. Transit drivers were generally dismissive of haptic seat warnings, due to periodic movement in seat and "rear-end fatigue" (Reference 3). However, Reference 1 notes that transit bus drivers are trained to "cover the brake pedal with their foot when approaching and entering an intersection to reduce their brake response time." If this behavior is typical, it would increase the likelihood that haptic brake pulsing would be perceived quickly by transit bus operators.

The factors of ambient vibration and no standard point of continuous body contact argue strongly against vibration-based warnings in heavy trucks. Views concerning heavy-truck CWS displays are consistently negative regarding the use of haptic warnings, due in part to potential learned or conditioned responses to haptic warnings that may interfere with intended evasive safety actions. Some heavy truck driver research participants exposed to haptic brake pulse warnings indicated a confusion regarding this feature (when there had been no training), misinterpreting it as a mechanical problem of some sort (Reference 5).

Design Issues

Reference 6 recommended haptic brake pulsing for frontal collision warning systems, despite the negative review received by drivers in a focus group. Identified advantages of haptic brake pulsing identified by these authors included not attracting passenger attention, providing a natural transition from warning to system control, and perspicuity under glare and high ambient noise.

Cross References

When to Use Auditory Warnings, 3-2
When to Use Visual Warnings, 4-2
When to Use Haptic Warnings, 5-2

References for the Design Guideline

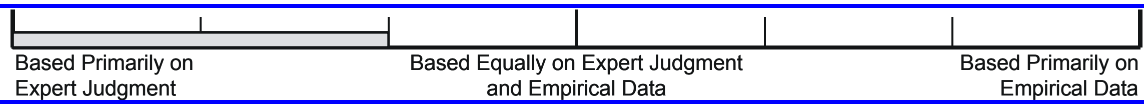
1. Reinach, S. and Everson, J. (2001a). Driver-vehicle interface requirements for a transit bus collision avoidance system (SAE Paper No. 2001-01-0052). *Proceedings of the Society of Automotive Engineers 2001 World Congress.*
2. University of California (UC) PATH and Carnegie Mellon University Robotics Institute (CMURI). (2004). *Integrated Collision Warning System Final Technical Report*. Washington, DC: Federal Transit Administration.
3. University of California (UC) PATH and Carnegie Mellon University Robotics Institute (CMURI). (2006). *Integrated Collision Warning System Final Technical Report*. Washington, DC: Federal Transit Administration.
4. Belz, S.M., Robinson, G.S., and Casali, J.G. (1999). A New Class of Auditory Warning Signals for Complex Systems: Auditory Icons. *Human Factors, 41*(4), 608-618.
5. Shutko, J. (2001). A*n investigation of collision avoidance warnings on brake response times of commercial motor vehicle drivers*. Unpublished master's thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.
6. Reinach, S. and Everson, J. (2001b). The preliminary development of a driver-vehicle interface for a transit bus collision avoidance system. *Intelligent Transportation Society of America Eleventh Annual Meeting and Exposition.*

Large Vehicle CWS Signal Design

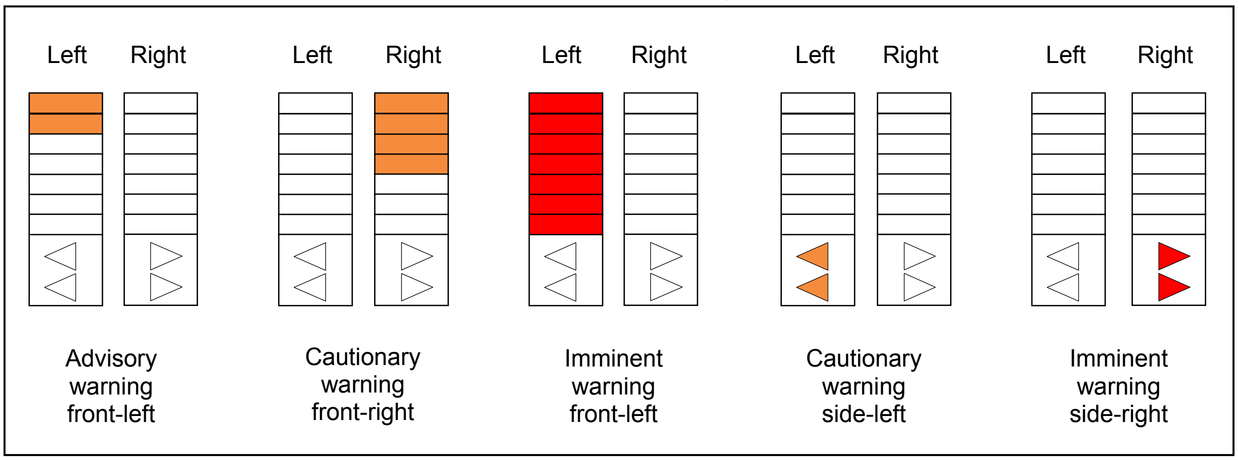
Introduction

Large vehicle CWS signal design refers to general guidance specific to heavy truck and transit bus CWS signal specification. If not explicitly discussed, the guidance found in preceding chapters of this document can be applied in the design of large vehicle warning signals.

Design Guidelines	
Warning Timing and Levels	• Large vehicles with longer braking distances require advance warning. • Multi-level warnings have broad applicability in large vehicles.
Warning Signal Intensity	• Warning signal intensity of all warnings should be sufficient to be readily perceived without startling the driver or alarming passengers. • Visual warning signal intensity must have an adequate range to deal with variable ambient illumination levels and glare. • Auditory signal intensity must be sufficient to overcome high ambient noise levels and adaptable to large fluctuations.
Warning Signal Design	• Hazard directionality information is important, especially in systems that integrate multiple detectors. • Carefully designed and selected auditory icons can be more effective than conventional, urgent-sounding auditory warnings.



Multi-Level Visual Warning Displays



The figure above is adapted from References 1 and 2, which provide descriptions of an integrated transit bus FCW and SCW visual display that provides progressive warning levels. The display consists of two LED displays mounted on the left and right driver's window pillars of the transit bus. The FCW displays consist of seven LEDs that can individually be illuminated either amber or red; and the SCW displays consist of two triangles that can also be individually illuminated with amber or red. Amber illumination is used for advisory and cautionary warnings; and red illumination is used for imminent warnings. For the FCW, the number of illuminated bars corresponds to the relative TTC, with more LEDs illuminated as the TTC becomes shorter.

Discussion

The differences in stopping distances between heavy trucks, buses, and passenger vehicles require that large vehicles travel with longer headways when following passenger vehicles to avoid rear-end collisions, and that FCW device thresholds must provide earlier warnings to drivers of large vehicles. This required earlier response to hazards has led to recommendations that heavy truck CWS should use progressive warnings to provide drivers with sufficient warning time to avoid forward crashes (Reference 3). Similarly, Reference 4 recommends a multi-stage collision warning to avoid hard braking and the resulting abrupt deceleration to unrestrained transit bus passengers.

Highly variable ambient lighting, including the use of passenger lighting, was identified as a design issue for transit bus CWS designs in Reference 3. Sun glare was also identified by transit bus drivers following their exposure to a prototype CWS visual display in Reference 1; in this case, drivers indicated that they had difficulty seeing the visual displays when driving directly into the sun. It was further reported in Reference 1 that transit bus operators identified driving into the sun as a time when a FCW system could be highly beneficial.

Auditory signal strength must be sufficient to overcome ambient noise levels without startling the driver or alarming passengers. Earlier research (Reference 5) and design guidance (Reference 6) 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. Reference 3 also identifies the potential problem that high signal strength might induce an inappropriate (e.g., startle) response and resulting hard braking by the transit bus operator.

Hazard directionality information is important, especially in systems that integrate multiple detectors. Large commercial vehicle drivers will most likely benefit from having additional information regarding the location of a detected hazard made readily apparent to them. Reference 4 identified the requirement that transit bus collision warnings indicate the direction of the hazard. The transit bus integrated CWS display (depicted in the preceding figure) used bar and arrow locations to indicate the side of forward and side hazards (Reference 1).

Auditory icons for forward collision warning (tire skidding) were found to elicit faster brake response times than a conventional, urgent-sounding auditory warning (Reference 7). Auditory icons that are suitable for the truck environment (tire skidding and loud horn honking) may not be suitable for transit buses, due to an actual or anticipated issue of passenger responses to such warnings. It is reasonable to assume that the use of salient and evocative auditory warnings, such as tire skidding and horn honking, could evoke negative or nuisance responses from transit bus passengers.

Design Issues

Chapter 5 provides a set of general guidelines for haptic warnings, though haptic warnings haven not been extensively studied in the context of heavy vehicles. The introduction of haptic warnings should follow careful design and testing to ensure a high level of warning comprehension and response compatibility. The haptic warning implemented in the heavy truck closed-course study reported in Reference 8 was misconstrued by approximately three of 20 drivers in that study condition. One participant indicated that the brake pulse led him to interpret the warning as a vehicle malfunction, which caused him to look at the instrumentation instead of the roadway and to depress the accelerator rather than braking (thinking that it was a fuel line blockage). Although this mode of warning holds some promise for transit bus applications, it requires thorough research and refinement prior to any implementation.

Cross References

How to Make Warnings Compatible with Driver Responses, 2-8
Auditory Warnings, Chapter 3
Visual Warnings, Chapter 4
Haptic Warnings, Chapter 5

References for the Design Guideline

1. University of California PATH and Carnegie Mellon University Robotics Institute. (2004). *Integrated collision warning system final technical report*. Washington, D.C: Federal Transit Administration.
2. University of California PATH and Carnegie Mellon University Robotics Institute. (2006). Integrated collision warning system final evaluation report. Washington, D.C: Federal Transit Administration.
3. Houser, A.; Pierowicz, J., and McClellan, R. (2005). *Concept of Operations and Voluntary Operational Requirements for Automated Cruise Control/Collision Warning Systems (ACC/CWS) On-board Commercial Motor Vehicles*. Washington, DC: Federal Motor Carrier Safety Administration.
4. Reinach, S. and Everson, J. (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.*
5. Robinson, G., Casali, J., and Lee, S. (1997). *The Role of Hearing in Commercial Motor Vehicle Operation: An Evaluation of the FHWA Hearing Requirement, Final Report*. Blacksburg, VA: Auditory Systems Laboratory, Virginia Polytechnic Institute and State University.
6. COMSIS Corporation. (1996). *Preliminary human factors guidelines for crash avoidance warning devices* (NHTSA Project No. DTNH22-91-07004). Silver Spring, MD: COMSIS.
7. Belz, S.M., Robinson, G.S., and Casali, J.G. (1999). A New Class of Auditory Warning Signals for Complex Systems: Auditory Icons. *Human Factors, 41*(4), 608-618.
8. Shutko, J. (1999). *An investigation of collision avoidance warnings on brake response times of commercial motor vehicle drivers.* Unpublished master's thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Large Vehicle CWS Driver Controls

Introduction

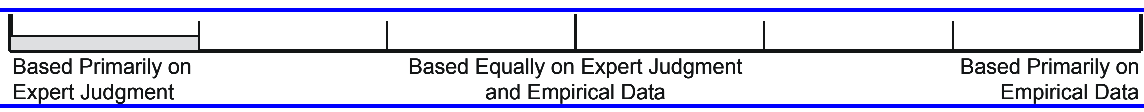
CWS driver control options include five CWS functions that might be placed under the driver's control. These functions have been identified primarily in passenger car CWS research and design guideline documents, as well as in a limited number of documents that directly addressed large vehicle CWS driver controls. The 1996 COMSIS Guidelines (Reference 1) recommended that each of these functions should be adjustable. However, practical considerations, along with very limited research findings, suggest that recommendations pertinent to CWS driver controls for large vehicles are substantially different from those for passenger vehicles. In addition, it is readily evident that there is a significant gap in available research upon which to base guidelines corresponding to this topic.

Design Guidelines

- Do not allow large vehicle drivers to permanently disable the CWS.
- Provide large vehicle drivers with the capability to temporarily reduce CWS sensitivity in highly cluttered settings (e.g., construction zones) where high frequencies of false and nuisance alarms would be encountered.
- Provide large vehicle drivers control of CWS warning visual brightness and auditory volume.

The recommendation column in the table below reflects a combination of available large vehicle and passenger vehicle CWS research and field test findings as well as expert judgment when research findings were not available.

CWS Function	Recommendation	Use Discrete Control	Use Continuous Control
On/Off Enables and disables the CWS.	Not Recommended	Yes	Not Applicable
Sensitivity (Warning Timing, Warning Threshold, Range, TTC) Controls the physical or temporal proximity threshold for which warnings are activated.	Recommended with reservations	Yes Between 2 and 6 sensitivity settings	Yes Precise Adjustment
Master Intensity Master control for intensity of all warning signals (i.e., visual, auditory, and haptic).	Recommended within limited range of settings	Yes Multi-Position	Yes Limited Range
Auditory Intensity Controls the intensity of all auditory warning signals.	Recommended within limited range of settings	Yes Multi-Position	Yes Limited Range
Visual Luminance Controls the intensity of the visual warning signals.	Recommended within limited range of settings	Yes Multi-Position	Yes Limited Range



Discussion

Virtually every passenger vehicle CWS currently on the market allows 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 current recommendation is that a system on/off function not be provided, as this would nullify the fleet owner/operator's intent in installing the system; however, there is not empirical evidence supporting the hypothesis that large vehicle operators would disable the system if given the opportunity.

System sensitivity settings are commonly implemented in CWS DVI designs and have been available to large-vehicle drivers in recent evaluations of FCW systems in both heavy-truck (Reference 2) and transit bus (Reference 3) operations. The potential value of temporarily reducing system sensitivity during driving in a relatively cluttered environment, thereby reducing the frequency of nuisance alarms, was noted in Reference 3. Reference 4 identified the potential difficulty of providing large vehicle drivers control over CWS sensitivity, noting that sensitivity controls may provide the benefit of increased large vehicle operator acceptance at the cost of delaying alerts until insufficient time is available to respond to an imminent hazard. The current authors are not aware of any evaluation of a large vehicle FCW that included the systematic variation of the range or availability of these sensitivity controls so that an evaluation of driver performance under different sensitivity setting conditions could be conducted. In the absence of available research findings, the present guidelines recommend that large vehicle system sensitivity could be temporarily reduced by drivers. 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.

A recently completed field operational test of heavy truck technologies that included a lane departure warning system reported that drivers frequently noted their annoyance with the audible alarm of that system, which was considered to be set too loud and could not be adjusted by drivers (Reference 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 large vehicles. Reference 6 provides an optional design recommendation of providing heavy truck audible warning control with a minimum setting of 65 dBA.

Design Issues

In the absence of a significant body of directly relevant research findings, the present guidelines recommend that large-vehicle system sensitivity could be temporarily reduced by drivers. 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.

A few references provided information that suggested the potential value of having minimum intensity levels that were dependent upon ambient noise or luminance levels. The suggestion by Reference 7 of providing an adaptive capability that presents an auditory warning with a set signal-to-noise difference could be implemented to establish an adaptive minimum audible warning intensity. 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 Reference 3; whereas the need for adequately low luminance for nighttime transit bus operations has been identified by other investigators (Reference 7). These extremes could be accommodated by a system that allowed large-vehicle driver luminance setting if it incorporated a capability to sense ambient illumination and have both minimum and maximum display luminance ratios for high and low ambient illumination conditions.

Cross References

Selection of Control Type, 6-2

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CHAPTER 11. TUTORIALS

Tutorial 1: Current State of CWS Technologies

Introduction

In this tutorial, we discuss the current state of technology used in FCW, LCW, and RDW systems implementation. Designers will be able to use this information as a starting point for developing ideas when determining the most appropriate and effective technologies to use in new CWSs as well as for improving current designs.

This tutorial is presented in three parts: 1) an overview of current technologies, 2) a technology review, and 3) a synthesis of CWS technology implementation. The overview of current technologies examines each technology in a general sense, including its purpose, features, capabilities, and limitations. Because many of the current technologies can be used across CWS applications, it is prudent to understand how the technologies function and what their capabilities and limitations are in order to determine the type of technology that is best suited for an application. Next, the technology review provides a detailed summary of the CWS technologies that are currently on the market or are expected to be available in the near future. This review was developed as part of the larger literature review performed by Richard, Campbell, and Brown (2005). Finally, the synthesis of CWS technology implementation provides a larger view of how the technologies identified in the technology review are currently being implemented in each of the three types of CWSs. Where information is available, we discuss the issues related to the implementation of each technology. However, we do not provide comments regarding the efficacy or quality of specific manufacturers' products.

Overview of Current Technologies

FCW, LCW, and RDW systems each use sensors that detect the vehicle's lateral and/or longitudinal proximity to objects or features on the roadway. The signals from these sensors are used to determine parameters such as TTC, headway distance/time, distance to lateral vehicles, lane position, etc. Warning displays are activated when one or more of these parameters exceed some pre-defined threshold. The current set of CWS products employs the following five types of sensors to measure the distances from which these parameters are derived:

- Radar
- LIDAR
- Ultrasonic detectors
- Infrared (IR) detectors
- Vision

A discussion of each of these technologies is presented below. For each technology, we provide an overview of the technology (what it is and how it works) followed by a discussion of the following aspects of the technology:

- Capabilities and limitations
- Level of maturity
- Health and safety aspects
- Cost relative to other collision avoidance solutions

Radar

Radar (Radio Detection and Ranging) is a technology that uses high-frequency electromagnetic (EM) waves to measure distance and differences in velocity. Two types of radar are used in CWSs: 1) impulse and 2) Frequency Modulated Continuous Wave (FMCW). Impulse radar measures the time required for radio waves to travel from a source to a detector (Ulaby, 1999). In a typical impulse radar system for CWS applications, one or more emitters are mounted in the bumper, side panel, or other appropriate location in the vehicle. The distance to an object is measured by determining the time-of-flight of an EM pulse that is emitted from the radar, reflected off of the object, and then detected by the radar. Distance is calculated based on the speed of the EM waves through the air. FMCW radar uses a frequency-modulated continuous radar wave such that the difference in frequency between the reflected wave and the source wave is proportional to the distance to the object ahead (Granet, 2003). In both types of radar, the Doppler effect can be used to measure the relative speed between the vehicle and the object ahead. The Doppler Effect is a change in radio wave frequency that is caused by the compression or expansion of the wave when there is a difference in speed between the transmitting source (host-vehicle radar) and the reflecting target (leading vehicle).

By convention, radar that operates at frequencies between 300 GHz and 30 GHz is sometimes referred to as millimeter-wave radar because the wavelengths of these signals range between 1 mm and 1 cm, respectively (Ulaby, 1999). Radar that operates at frequencies less than 30 GHz is sometimes referred to as microwave radar.

Capabilities and limitations: Radar systems used in CWSs must operate at frequencies in "atmospheric windows," frequencies at which the signals are not affected by atmospheric absorption (Ulaby, 1999). Radar systems most commonly used in CWSs operate at 24 GHz and at 76/77 GHz, and research is ongoing to develop systems that operate at 94 GHz (e.g., Moldovan et al., 2004). The size of the sensor is inversely proportional to the operating frequency, so smaller units can be manufactured by using sensors that operate at higher frequencies. However, cost and circuit complexity increase as operating frequency increases. In addition, the detection range of lower frequency radar is not as great as higher frequency radar.

Impulse radar typically operates at lower frequencies than those of FMCW radar, but they still can provide detection resolution similar to FMCW at a much lower cost (Granet, 2003). However, the detection range of impulse radar is not as great as that of FMCW radar. Also, impulse radar is more susceptible to EM interference. Both impulse and FMCW radar are relatively insensitive to the environmental conditions of fog, rain, snow, and dirt on the sensor (Granet, 2003; Marsh, 2003).

Maturity of the technology: Radar technology has been used to detect aircraft since before World War II. The emergence of the Monolithic Microwave Integrated Circuit (MMIC) and other semiconductor technologies has made it possible to miniaturize radar systems to a scale that is suitable for automotive applications. Although the use of radar in CWS applications is relatively new compared to other radar-based applications, the basic concepts and issues related to radar design and operation are well known.

Health and safety aspects: EM radiation at the frequencies used in radar systems has been shown to be hazardous to humans when exposed to high enough power densities (OSHA, 2006). However, there is insufficient research to definitively assess the health risk related to the effects of long-term exposure to low-level emissions such as those used in radar for CWS applications. One finding suggests that there may be an association between the use of speed detection radar and the incidence of testicular cancer in police officers, although it was not clear whether radar use was a causal factor in the development of the cancer (Davis et al., 1993 in Lotz, Rinsky, & Edwards, 1995). Nonetheless, several standards, such as Institute of Electrical and Electronics Engineers/American National Standards Institute (IEEE/ANSI) 1991 standards and the World Health Organization (WHO) Criteria 137 of 1993, provide guidance regarding safe levels of exposure to EM emissions. Currently, there are no Federal safety regulations regarding exposure to radio frequency emissions at the frequencies and power levels used in radar for CWS applications. This issue may be of increasing concern as the number of vehicles equipped with radar-based CWSs increases.

Relative cost: Most expensive.

LIDAR

LIDAR (LIght Detection and Ranging, Laser Imaging Detection and Ranging, or laser radar) is a laser-based analog to radar and works in much the same fashion (Jones, 2001; Granet, 2003). Time-delay, intensity, and/or phase characteristics of back-scattered (reflected) EM radiation from a laser are used to determine the distance to an object or surface. As in radar, the Doppler Effect can be used to determine the relative velocity between the host vehicle and the lead vehicle. Two techniques exist for detecting objects and determining relative velocity. One technique uses a high-power pulsed beam of IR light, while the other modulates the light beam with a sinusoidal signal.

By convention, LIDAR outputs are generally specified in terms of wavelength rather than frequency. LIDAR systems used in CWS applications typically operate in the near-IR region of the EM spectrum, between 750 nm and 1000 nm (Bishop, 2005). A single laser beam used in LIDAR has a very narrow field of view—typically one degree. A LIDAR system may employ an array of lasers with non-overlapping fields of view to achieve an adequate overall area of coverage.

Capabilities and limitations: LIDAR sensors offer long detection range, high directionality, and fast response time (Granet, 2003). The drawback to these systems is that they are subject to visibility limitations: dirty sensor, fog, rain, etc. In addition, roadway features such as retro-reflective lane markings, guardrails, and construction barriers are highly visible and may be interpreted by the LIDAR system as a vehicle traveling at the same speed as the host vehicle (Widmann et al., 2000). Signal processing algorithms may be employed to properly interpret these objects as well as adjust for limited visibility issues.

Maturity of the technology: Although first generation LIDAR was sensitive to adverse weather conditions, advances in the signal processing have substantially improved its ability to filter out unwanted atmospheric noise such as fog (Bishop, 2005). Because of the cost savings over radar, there is sufficient interest in LIDAR-based sensing technology to expect continued improvements in LIDAR robustness.

Health and safety aspects: LIDAR lasers present the same safety risk that is common to all lasers (Laser Institute of America, 2006). A safe power level must be maintained to prevent corneal and retinal damage when looking directly into the lasers or when viewing laser energy that is mirrored from highly reflective surfaces. This issue is of particular concern because the IR laser does not operate within the visible spectrum, and an individual may receive damaging levels of exposure without being aware of the laser emissions. However, lower-power lasers may emit levels of laser light that are not hazardous. The ANSI Z136 series of standards provides standards and practices for laser safety (ANSI, 2000).

Relative cost: Less expensive than radar but more expensive than vision.

IR Sensing

Two types of sensing techniques are used in IR-based CWSs: active sensing and passive sensing. Active IR sensing technologies use an IR LED and a corresponding IR detector cell to measure lateral distances between points on the vehicle and detectable characteristics on the roadway surface (e.g., Citroën, n.d.). Specifically, the IR detector cell senses variations in the intensity of reflections from the IR beams emitted by the LED onto the roadway surface. Active IR sensing can also be used for range finding, wherein the intensity of scatter is measured as the IR reflects off of nearby object surface (Luckscheiter, 2003). Passive IR sensing measures the thermal energy emitted by objects in the vicinity of the sensor.

Capabilities and limitations: The advantage of IR sensors is that they are inexpensive and small in size. However, their ability to determine precisely the distance to a detected object is poor, and they have slow response times. In a study of a rear impact CWSs for transit buses, Luckscheiter (2003) found that characteristic images detected by IR sensors can include high-reflectance areas (hot spots) that are spatially separated by dark areas. For example, a lead vehicle might produce simultaneous hot spots from the bumper, C-pillar, rear windshield, and rear-view mirror. These hot spots require extra processing to determine whether they belong to a vehicle. Also, the characteristics of short-wavelength IR backscatter may change abruptly as the viewing angle changes. The resultant changes in hot spot reflections may cause the detected vehicle to instantaneously disappear from the sensor's view. The use of long wave IR is expected to alleviate the problem. Finally, vehicles with dark paint or shallow angle geometry (e.g., sports cars) may not reflect sufficient IR energy to exceed the detection threshold.

Maturity of the technology: IR sensing is not a major technology for range-finding in collision warning systems. Active IR sensing, as used in current applications, is arguably one of the simpler technologies to implement. In order for passive IR sensing to become more widely used, techniques for improving range resolution and reflectivity issues must be refined.

Health and safety aspects: IR energy can cause damage to the cornea, lens, and/or retina depending on the wavelength, intensity, and duration of exposure (Mathes, n.d.). Several international organizations, such as the WHO, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), and the American Conference of Governmental Industrial Hygienists (ACGIH), have published standards for acceptable exposure conditions. Many of these guidelines are based on suggested threshold limits published by the ACGIH (www.acgih.org).

Because passive IR sensors do not produce IR emissions but rather detect existing IR light, there are no associated health risks caused by the technology.

Relative cost: Inexpensive.

Ultrasonic Sensing

Like impulse radar, ultrasonic sensors measure the time-of-flight required for signal pulses to travel from a source to a detector. This signal consists of acoustic pulses at frequencies above the audible range. The ultrasonic transducer radiates acoustic pulses away from the vehicle and measures the pulses that reflect off of the surfaces of objects that are within the sensor's designed range and field of regard. The elapsed time is measured from the time the pulse is emitted to the time the pulse is detected. The distance to the object is then calculated based on the speed sound in air.

Capabilities and limitations: Ultrasonic transducers are suitable for applications where short-range measurements are required (Granet, 2003). The main advantages of these sensors are their low cost and small size. However, these sensors may not detect objects that have poor acoustic reflectivity (e.g., pedestrians wearing sound-absorbing clothing). Also, ultrasonic transducers are often sensitive to temperature variations.

Maturity of the technology: The basic technology of range-finding with ultrasonic transducers has existed since the early 1900s. More recently, ultrasonic transducers have been used with some success in parking assist applications (Bishop, 2005). The basic design issues and operational challenges of ultrasonic sensing are well known.

Health and safety aspects: No health or safety issues were identified in the technology review.

Relative cost: Inexpensive.

Vision

Vision-based systems use one or more digital video cameras to view the characteristics of the roadway and/or objects near or around the vehicle. The digital images are processed using sophisticated motion analysis, edge detection, and/or pattern recognition algorithms to determine parameters such as headway distance, closing rate, lane position, and presence of objects in the vehicle's path.

Capabilities and limitations: Vision systems do not provide a direct measurement of distance. Instead, the distance must be calculated based on the geometry of the captured image, a process that requires powerful signal processing. However, because the technology is based on visual images, the application and capability of vision-based systems are limited only by the computing power and speed available to process the image. Therefore, one of the strengths of vision technology is its versatility.

Vision-based systems share the same disadvantage that other optical systems (LIDAR and IR sensing) suffer: these systems are sensitive to adverse environmental conditions, such as dirt on the windshield or camera lens, fog, rain, and snow. Image processing algorithms can reduce the effects of these factors.

Maturity of the technology: Vision technology is relatively new in CWS applications. However, continual increases in computing power and improvements in image processing algorithms have made vision systems a viable—and commercially available—CWS alternative.

Health and safety aspects: No safety or health issues were identified in the technology review.

Relative cost: Less expensive than radar or LIDAR but more expensive than IR or ultrasonic.

Technology Review

To determine the current state of technology for forward collision, lane change, and road departure collision warning systems, a technology review was performed. This review provides a summary of collision warning technologies that are currently available or will be available in the near future. The results of this review are presented in the form of a table describing the characteristics of each CWS.

A literature search was conducted to identify the technologies to be included in the review. Sources included books, trade journals, product brochures, manufacturer's press releases, manufacturers' Web sites, and trade magazine Web sites. Candidate technologies were then evaluated for appropriateness of inclusion, as described below. Technologies deemed out-of-date or inappropriate were removed from further consideration. After identifying the products to be included, the sources were reviewed to determine the characteristics of each CWS including type of system, target market, operational concept and features, method of presenting warnings to the driver, and additional information. Wherever possible, the makes and models of vehicles equipped with the technology were identified. In addition, information regarding collaboration of efforts between companies either for joint product development or for production was identified.

Technologies were chosen for inclusion in the review based on the following criteria:

- Relevance to forward collision, lane change, and road departure warning systems.
- Product availability. Products that are currently available, are expected to be available by the year 2007, or are mature enough to be demonstrated on a concept car were included in the review. Older products that are no longer available, have evolved into a different product, or have been purchased by another vendor were excluded from the review.
- Packaging. Complete CWSs or devices were included in the review. Component parts of a larger CWS (e.g., radar unit to be sold for inclusion in a CWS) were not included in the review.

Some ACC technologies were included in the technology review. In and of itself, ACC does not provide collision warning; however, the latest generation of ACC products features auditory, visual, or haptic warnings when a vehicle cuts into the lane ahead or if the closing rate is too high. Only ACC systems that offer these warnings were included in the review.

Table 11-1 lists the technologies included in the review. The table does not represent a complete, exhaustive list of all technologies available, but rather lists key players that are developing and providing collision warning technologies. It is important to note that the information presented was harvested from manufacturer's specifications, product brochures, press releases, and other publications; this technology review does not make any judgments or statements about the veracity of stated specifications and features. Also noteworthy is that representative DVI implementations are provided for many of these technologies. The final DVI configuration for many of these products depends on the original equipment manufacturer (OEM) requirements for the specific vehicle in which the technology will be implemented.

Table 11-1 includes the following fields:

Manufacturer	The name of the product manufacturer.
Product	The trade name of the collision warning product. If the reviewed literature did not specify a product name, a brief descriptive name is given in this field. For manufacturers that provide families of technologies, the individual products are listed separately.
Type	An acronym indicating the type of collision warning system. Products that list more than one type generally represent integrated CWS solutions.
Market	The target market for the technology (e.g., light vehicle, heavy vehicle, bus). For some products, additional information that refines the market scope is also given.
Operational Concepts and Features	The technologies used to implement the collision warning system and key characteristic features of the product as defined in the manufacturer's specifications, product brochures, press releases, and other trade sources.
DVI Approach	The methods used to present warning information to the driver.
Comments	Ancillary information regarding the implementation of the technology including such topics as make and/or model of vehicles using the technology, availability, third party manufacturers, and corporate partnerships for joint development, etc.
Source	References to the sources used in developing the table. The corresponding list of references is found in Appendix A.

Table 11-1. Summary of current and emerging collision warning systems

Manufacturer	Product	Type	Market	Operational Concepts and Features	DVI Approach	Comments	Source[1]
Aisin/ Toyota	Rearview System	LDWS	• Light Vehicle	• Rear-looking camera with lane detection • Tracks lane markers	• Auditory warning (beep) if the vehicle is about to cross a highway lane	• Jointly developed with Toyota Motor Corporation • Same rear-view camera also used for parking assist	1
AssistWare Technology	SafeTRAC	LDWS	• Heavy Vehicle (North America)	• Forward-looking camera with lane detection • Tracks lane markers, road edge, oil strips in center area, etc. • Can track relative lane-keeping accuracy over time to indicate fatigue • Continuous indication of vehicle position within the lane	• Audible alarm if vehicle begins to depart the lane or cross into another lane without turn signal activated • Seat vibrator haptic display	• Kenworth • Volvo • Available since 2000 • Used in GM/NHTSA collision warning program for lane tracking • Core technology Licensed to Visteon	2 (pp 101-102), 3, 4
Bosch	Adaptive Cruise Control	ACC	• Light Vehicle	• 77 GHz radar • 100 m range • Designed to work from 0 km/h for stop-go traffic conditions • Pre-braking in critical situation	• Haptic warnings (brake pulse and seat-belt tightening) planned for 2006	• Fiat Stilo 2001 • BMW	5, 6, 7
Bosch	Predictive Safety System	BSW LCA	• Light Vehicle	• 24 GHz radar (BSW) • Vision (LCA)	• Auditory and/or visual signals • Haptic signals (brake pulse, seat-belt tightening pulse)	• Expected 2006	7, 8, 9
Citroën	Lane Departure Warning System	LDWS	• Light Vehicle	• 6 IR sensors (IR LED and detector) mounted under front bumper • Tracks lane markers	• Haptic display (localized vibration in seat)	• Models with incorporated LDWS vary from country to country	10
Continental	ACDIS Active Distance Support	ACC FCW	• Light Vehicle	• 24 GHz radar forward sensing • Full speed range ACC (30-200 km/h) • Pre-braking even when ACC is not activated	• Auditory and visual warnings if automatic braking exceeds 0.3 g • Haptic warning in gas pedal on potential threat whether or not ACDIS is activated • Can brake vehicle to standstill and inform driver when lead vehicle has moved away	• Cadillac STS • Cadillac XLR • Currently available	11, 12, 13

[1] All sources are correspondingly numbered and listed in Appendix A.

Manufacturer	Product	Type	Market	Operational Concepts and Features	DVI Approach	Comments	Source[1]
Continental	Lane Departure Warning system	LDWS	• Light Vehicle	• Forward-looking camera with lane detection	• Auditory (virtual rumble strip) • Visual • Haptic (steering wheel or seat vibration)	• Planned for 2006	11
Delphi	Forewarn Smart Cruise Control	ACC FCW	• Light Vehicle	• 76 GHz radar (ACC/FCW) • Forward detection range 150 m • Active braking up to 0.3 g • Driver-adjustable sensitivity • Full range ACC to 0 km/h	• Depends on OEM requirements • Auditory and visual warnings	• Expected in Europe 2006	14, 15, 16
Delphi	Forewarn Lane Departure Warning	LDWS	• Light Vehicle	• Forward-looking camera • Tracks lane markers up to 25 m ahead • Camera mounted behind wiped area of windshield • Blocked sensor notification	• Depends on OEM requirements • Auditory (tones, virtual rumble strips), visual, or haptic warnings	• 2003 Jaguar XKR	17
Delphi	Forewarn Infrared Side Alert	LCA	• Light Vehicle	• Passive IR sensors integrated into mirrors, taillights, or side fascia • Warning is triggered if threat vehicle exists when turn signal is activated	• Visual indicator in mirrors • Auditory warning if maneuver unsafe	—	18
Delphi	Forewarn Headway Alert	FCW	• Heavy Vehicle	• 76 GHz radar • Range of 402 ft (120 m)	• Auditory, visual, or haptic depending on installation	—	19
Denso	Pre-Collision System	FCW	• Light Vehicle	• Millimeter-wave Radar • Auto-braking	• Haptic (seat belt tightening)	• Lexus LS 430	20
Eaton	VORAD Blindspotter	LCA	• Heavy Vehicle	• 24 GHz Doppler radar • Right- and left-side blind spot sensing • Radar oriented at right angle to the truck • Active sensing zone designed to be 2–10 ft to cover adjacent lane	• Red (vehicle detected) and yellow (no vehicle detected) LEDs mounted in line-of-sight with side mirrors • Auditory tone when turn signal active and vehicle detected	• Can be used independently or in conjunction with SmartCruise and Forward Collision Warning	2 (p 113), 19
Eaton	VORAD SmartCruise and Forward Collision Warning	ACC FCW	• Heavy Vehicle	• 24 GHz Doppler radar • Automatic braking and downshifting (ACC) • Emits warning when lead vehicle is detected (both)	• Multi-level visual/auditory warning • Beep rate increases with decrease in headway	• Based on TRW Autocruise sensor	2 (p 136), 21

Manufacturer	Product	Type	Market	Operational Concepts and Features	DVI Approach	Comments	Source[1]
Ford	CMbB	CMbB LDWS	• Light Vehicle	• Video/radar combined system • Auto-braking to full ABS braking • Forward-looking camera mounted behind the windshield tracks lane markings (LDWS)	• Haptic (auto-braking)	• Mercury Meta One concept car (expected crossover vehicle 2007) • Volvo V70 (expected soon) • Camera and radar by Delphi Delco Electronic Systems • Developed in cooperation with Volvo	22, 23, 24
Ford	ACC Forward Alert System	ACC FCW	• Light Vehicle	• Radar • Auto-braking to full ABS braking	• Visual, auditory (buzzer)	• Jaguar S, XJ and XK	23
Ford	LDWS	LDWS	• Light Vehicle	• Forward-looking camera mounted behind the windshield monitors lane markings	• Visual, auditory (buzzer), haptic (localized seat vibration)	• Various concept cars	23, 24
GM Europe	SAFETECH	ACC LDWS	• Light Vehicle	• LIDAR (ACC) • Vision (LDWS)	• Visual • Auditory	• Opel/Vauxhall Vectra; Saab 9-3 • Other Epsilon platform derivatives	25, 26
Hella	Lane change assistant	LCA	• Light Vehicle	• Two 24 GHz radar sensors mounted in front bumper with range up to 50 m • Third 24 GHz radar in the rear can increase range to 120 m	• Visual, auditory, or haptic	• Expected 2006	27
Hella	Lane departure warning	LDWS	• Light Vehicle	• Forward-looking camera mounted in rear-view mirror	• Visual, auditory, or haptic	• Expected 2007	27
Honda	ASV-3	CWS	• Light Vehicle • Motorcycle	• Radar + vision	• Auditory, visual, and haptic warnings (brake or accelerator vibration, applied steering torque)	• Still in research—no date for release in production vehicles	28
Honda	Collision Mitigation Braking System	CMBS	• Light Vehicle	• Millimeter-wave radar • Warns driver if closing rate falls below a time/distance threshold • Automatic braking if driver response insufficient	• Visual warning (BRAKE text on IP) • Auditory (continual series of beeps) • Haptic (seat belt tightens)	• Acura RL	28, 29
Honda	HIDS (Honda Intelligent Driver Support)	ACC LDWS	• Light Vehicle	• Millimeter-wave radar (ACC) • Operating range 40-100 km/h • Auto braking to 0.2 g • Forward-looking camera (LDWS)	• Flashing orange icon in dash indicates lane departure	• Inspire Avanzare • Option on certain Accord and Accord wagon models	30

Manufacturer	Product	Type	Market	Operational Concepts and Features	DVI Approach	Comments	Source[1]
MAN	ACC Lane Guard System	ACC LDWS LCA	• Bus	• Forward-looking camera monitors lateral movement of vehicle • Parametric lateral range or lane marker tracking • Automatically activates above 60 km/h—driver defeatable • Warns of unsafe lane change maneuver	• Auditory alarm	• Based on Valeo/Iteris LDWS • EvoBus GmbH • Mercedes-Benz Omnibusse • MAN Busse	31, 32
Mercedes	Distronic	ACC FCW	• Light Vehicle	• Radar • Auto-braking to 0.2 g • Designed range of 150 m	• Audible and visual (red triangle icon on the IP) warnings if required braking exceeds 0.2 g	• Mercedes S-Class, E-Class, CLK-Class	33, 34
MobileEye	Lane Change Assist	LCA	• Light Vehicle	• Right- and left-side sensing (monocular cameras on side-view mirrors) • Detects lane markings and moving and stationary vehicles in adjacent lanes • Provides warning if lane change maneuver is unsafe • Close-by vehicles detected by motion analysis; farther vehicles detected by pattern recognition • Target vehicle lane position monitored to reduce nuisance alarms	• Visual indicator located on side mirror or on dash • Depends on installation/implementation	• Available 2006 • Based on Mobileye EyeQ Application Specific Integrated Circuit (ASIC) • STMicroelectronics to develop second generation ASIC	2 (pp 114-115), 35, 36
MobileEye	AWS	FCW LDWS SGA	• Light Vehicle • Heavy Vehicle • After-market Installations	• Forward-looking camera mounted behind rear-view mirror • 3-parameter road model accounts for lateral lane position, slope, and curvature • Multiple-lane models (i.e., urban roads, merging lanes, exit lanes) to accommodate best match for conditions • Processes raindrops and windshield wiper motion during heavy rain to retain integrity of signal	• Auditory and visual warnings (FCW, SGA) • Auditory virtual “rumble strip” warning (LDWS) • Haptic seat vibration warning • Top-of-dash visual display indicates: - headway time (numerical display) - distance to lead vehicle (converging dashed lines), - system activation (icon)	• Cadillac STS SAE 100 concept car • Available since 2004 • Based on Mobileye EyeQ Application Specific Integrated Circuit (ASIC) • STMicroelectronics to develop second generation ASIC	2 (pp 103-104), 37, 38, 39, 36

Manufacturer	Product	Type	Market	Operational Concepts and Features	DVI Approach	Comments	Source[1]
Mobileye	Adaptive Cruise Control	ACC	• Light Vehicle	• Forward-looking camera mounted behind rear-view mirror • Throttle and brake control for ACC function • Generates signal when vehicle cuts in • Automatically disabled under poor visibility conditions	• Depends on OEM requirements	• Based on Mobileye EyeQ Application Specific Integrated Circuit (ASIC) • STMicroelectronics to develop second generation ASIC	40, 36
Mobileye	Pedestrian Protection	FPD	• Light Vehicle	• Forward-looking camera mounted behind rear-view mirror • Determines whether pedestrian is in collision path • Warnings for individuals or crowds	• Depends on OEM requirements	• Based on Mobileye EyeQ Application Specific Integrated Circuit (ASIC) • STMicroelectronics to develop second generation ASIC	41, 36
Preco	PreView Collision Warning System	LCA RCA	• Heavy Vehicle (construction and commercial)	• Microwave Radar • CAN communications protocol for interfacing with other displays	• Visual: group of lights • Auditory: beeping • Beep/flash rate increases as vehicle closes	—	42
Siemens VDO	Advanced Driver Assistance Systems	BSW LCA LDWS	• Light Vehicle	• 24 GHz radar • Blind spot detection from 10 km/h up and lane change assist from 60 km/h up	• Visual • Haptic (steering wheel vibration)	• Expected 2007	43, 44
Toyota	Adaptive Cruise Control	ACC FCW	• Light Vehicle	• Radar • Full range ACC (0 to 100 km/h) • Automatic braking if driver response insufficient • Will slow to complete stop	• Visual and auditory warnings if lead vehicle stops	—	45, 46
Transportation Safety Technologies	Eagle Eye	BSW	• Heavy Vehicle	• Up to 7 ultrasonic sensors detect side and rear proximity • Sensors can be placed anywhere on vehicle • Detection range of 10 ft	• Numeric readout of distance to hazard vehicle • Multi-stage visual (yellow light if > 5 ft away; red light if < 5 ft away) • Auditory ("Geiger counter-like tones that change intensity as vehicle closes or single/double tones at range of 10/5 ft	• Also provides backing warning	47

Manufacturer	Product	Type	Market	Operational Concepts and Features	DVI Approach	Comments	Source[1]
TRW	Autocruise AC20	ACC	• Light Vehicle • Heavy Vehicle	• 77 GHz Radar • 200 m range	• Depends on OEM requirements	• Volkswagen Phaeton • Sensor jointly developed with Visteon	48, 49, 50
Valeo/Iteris	LaneVue (formerly Iteris AutoVue)	LDWS	• Light Vehicle • Heavy Vehicle • European Motor Coach	• Forward-looking camera with lane detection • Tracks lane markers • Sensor viewing proximity very close to the front of the vehicle • Operates at speeds > 45 mph	• Directional auditory warning (auditory tone, virtual rumble strip) • Haptic warning (vibration in driver's seat) for busses	• Infinity FX45, M45, WI45, Citroën C4 and C5 • Factory option from several truck mfg., e.g., Mercedes Actros • Jointly developed with Iteris from the AutoVue system	2 (pp 102-103), 51
Valeo/Ratheon	Multibeam FMCW	LCA BSW	• Light Vehicle	• 24 GHz radar • Right- and left-side sensing (sensors under right and left side of rear bumper fascia) • Designed system range of 40m • Designed FOV of 150 degrees	• Flashing light mounted in rear-view mirror or in door mirror • Flashing red light on dashboard with arrow icon pointing direction of threat vehicle	• Expected 2006 • Cadillac STS SAE 100 concept car • Jointly developed with Raytheon • 2002	2 (p 114), 36, 52, 16
Visteon	Adaptive Cruise Control	ACC	• Light Vehicle	• Forward-looking 77 GHz radar • Combines forward radar with yaw and steering data to determine threat targets • Automatic braking	• Haptic	—	53, 49
Visteon	Side Object Awareness System	LCA RDCW	• Light Vehicle	• 24 GHz radar • Right- and left-side sensing • Designed detection range of 6 m (upgradable to 30 m) • Programmable alert zones (laterally and longitudinally) • Designed to reduce false/nuisance alarms through threat assessment • Hidden installation	• Illuminated icon integrated into side mirror	—	2 (pg 114), 53
Volvo	Advanced Warning System	ACC FCW	• Light Vehicle	• Radar • Automatic braking if system determines manual braking is insufficient	• Red warning signal • Projects a virtual brake light on windshield	• Volvo safety concept car (2005)	45, 54
Volvo	BLIS (Blind Spot Information System)	LDWS	• Light Vehicle • Heavy Vehicle	• Vision • Right- and left-side sensing (cameras on side-view mirrors)	• Warning light near door mirror when vehicle enters critical zone	• 2005 XC70 and XC90 all-wheel-drive wagons, the V70 wagon, S60 and S80	45, 55

Synthesis of CWS Technology Implementation

This section is a synthesis of the information gleaned from the technology review and describes in a broader sense how the technologies are currently being implemented in ACC/FCW, LCW, and RDW devices. The utilization and specific characteristics of each of the technologies are discussed for each CWS. Examples of manufacturers' systems that illustrate the characteristics of the technologies are provided; however, the discussions are not intended to represent all products from all manufacturers.

Technologies for ACC and FCWs

The majority of FCW systems currently in use have been implemented as part of an integrated ACC/FCW system (Bishop, 2005). ACC systems with integrated FCW provide visual, auditory, and/or haptic warning responses when a conflicting vehicle is detected in the forward path at a predetermined distance ahead. For many of the available systems, these responses are not intrinsically linked to the detection technology and can be tailored to the specific needs of the OEM. These manufacturers provide the OEM with the ability to choose the type of warning modality and its method of implementation. Some ACC/FCW systems, such as those from Bosch (Anonymous, 2004b), Delphi (2005a), Continental (Continental-Temic, 2004) and Toyota (JAMA, 2004a) operate at a full range of vehicle traveling speeds from freeway speeds to a complete stop. In contrast, the Nissan system will not operate when the vehicle is traveling at less than 5 km/h (Bishop, 2005). Collision Mitigation Braking Systems (CMBS) also fall into the category of automatic braking systems and may provide forward collision warnings if the closing rate or distance falls below some threshold.

Current ACC and FCW systems use three sensing technologies for determining distance to lead vehicles, including radar, LIDAR, and vision-based systems. Radar is the most commonly used technology for ACC/FCW applications (Bishop, 2005). Most of these systems use either FMCW or pulsed radar (TRW's system uses frequency shift keying (FSK) radar, a variation of FMCW radar) and operate at frequencies of 76–77 GHz (Schollinski, 2004). One exception is the Eaton Vorad ACC, which uses a 24 GHz Doppler radar (Bishop, 2005). These systems are designed to detect forward vehicles at distances from 120 m to as much as 200 m. Some systems, including the Visteon, Bosch, Continental-Teves, TRW, and Honda systems, use an array of two to five emitters that cover a total field of view of 10 to 40 degrees (Scholinski, 2004; Bishop, 2005). The Delphi system used in the Jaguar uses a single emitter that is mechanically swept back and forth to provide adequate horizontal coverage. In addition, some systems are designed to provide wider beam widths for close-range sensing to detect "cut-ins" in the near field and narrow beam widths for farther-range sensing to reject targets in adjacent lanes in the far field (Bishop, 2005).

Current and emerging LIDAR-based systems use a swept array of 5 to 16 lasers with non-overlapping fields of view (e.g., see Widmann, 2000). The detection envelope is covered by sequentially switching between laser beams, each of which covers a one degree field of view. For example, Hella's ACC system uses 16 laser beams to provide 16 degrees of coverage with a maximum detection range of 200 m and a headway regulation range of 150 m (Hella, 2006). Denso uses a single laser with a rotating polygonal mirror to achieve 36 degrees of horizontal coverage (Bishop, 2005). The specified detection distances for LIDAR devices typically vary between manufacturers. For example, Nissan's ACC laser sensor, manufactured by Omron, uses an 860-nm pulsed laser diode with a detection range of 130 m, while the detection range of the Delphi Delco "Forewarn" system is 230 m (Coffey, 2001).

Vision has found only limited utility in ACC/FCW applications. The MobileEye system (www.mobileye.com) provides a modular, vision-based sensing integrated circuit that is being used in both OEM and aftermarket FCW applications for both light and heavy vehicles (Bishop, 2005). This system uses a forward-looking camera mounted behind the rear-view mirror to capture video data that are processed to determine the distance to the forward vehicle. The image processing algorithms include multiple lane models and a three-parameter road model that accounts for lateral lane position, slope, and curvature. To retain the integrity of the signal, the image processing algorithms remove external noise sources, such as raindrops and windshield wiper motion. This system is also used in their Lane Departure Warning (LDW).

Technologies for Lane Change Warnings

This class of warning technology includes several types of collision warning products. These are marketed as Blind Spot Warning (BSW), LDW, and Lane Change Assist (LCA) systems. All of these warning types detect lane position and determine whether it is safe to cross into an adjacent lane. BSW systems determine whether a vehicle is positioned in the driver's blind spot. LDW systems provide a warning if the vehicle is about to cross into an adjacent lane when the turn signal is not active. LCA systems warn when a conflicting vehicle is either approaching or present in the adjacent lane when the turn signal is active. These are somewhat loose definitions, and they are sometimes used interchangeably between manufacturers.

The capability and timing of LCWs depend not only on the detection range, but also on the field of view (the angular field of regard that the sensor can "see"). The detection range is largely dependent on the type of technology used to deploy the system as well as on the detection requirements for the type of system. BSW systems detect laterally oriented objects; therefore, they require shorter-range sensing capability compared with FCW, LDW, and LCA systems. Typical detection ranges for BSWs vary from 3 m to 40 m, depending on the design strategy and the type of technology used to implement the warning (Bishop, 2005). The detection range for LDW and LCA systems require longer-range sensing because they must look not only laterally but also longitudinally to determine lane position and to detect the presence of conflicting vehicles in the adjacent lane. The detection ranges for these systems are generally from 25 m to 120 m depending on the type and configuration of sensors (e.g., see Hella, 2006). The field of view depends on the specific capabilities of the sensors in use and the quantity and arrangement of the sensors.

Currently, LCW systems use four sensing technologies, including radar, IR sensing, ultrasonic sensing, and vision. Radar is used predominantly in BSW and LCA systems and to a limited extent in LDW systems. The radar sensors used in these systems operate almost exclusively at 24 GHz. Features of these systems may include left- and right-side sensing, 150-degree field of view, and detection range of up to 40 m (Bishop, 2005).

IR sensing is used in the Delphi "Forewarn Infrared Side Alert" LCA application (Delphi, 2005b) and the Citroën LDWS application (Citroën, n.d.). In the Delphi system, passive IR sensors are integrated into mirrors, taillights, or side fascia in order to determine the proximity of other vehicles. In the Citroën application, six active IR sensors (i.e., IR LED and detector) are fitted under the front bumper, three on each side. Lane departures are detected by variations in the reflections from the IR beams emitted by the LED onto the road. The sensors can detect markings in white and yellow as well as the red and blue markings that are used in some European countries. The system tracks the lane markers and triggers an alarm when the lane is exceeded without the activation of the turn signal.

Ultrasonic sensing technology was found in products from two manufacturers: Safety Enterprises “Lookout” (Anonymous, 2001a) and Transportation Safety Technologies “Eagle Eye” (www.tst-eagleeye.com). Both are designed for use in heavy vehicles. Depending on the application, this technology also can be used as a backing alert. The typical detection range for the ultrasonic sensors in these applications is approximately 3 m. One advantage in using these sensors is that they can be placed anywhere on the vehicle to detect side and rear proximity.

Vision-based systems are used extensively in LDW systems and to a limited extent in BSW and LCA systems. Most of these systems determine the lane position based on video data from a forward-looking camera that is used to detect upcoming lane markings and other roadway features. However, Toyota’s “Rearview” system uses a rear-looking camera to determine lane position based on a rear view of the roadway markings and features (Bishop, 2005). The Valeo/Iteris “LaneVue” (formerly the Iteris “AutoVue”) tracks the lane markers with a viewing proximity that is very close to the front of the vehicle in order to maintain precise measurement of lane position, particularly in adverse weather conditions such as fog (Bishop, 2005). Features of vision-based LDW systems may include tracking of lane markers up to 25 m ahead, automatic activation of the LDW system when the vehicle exceeds 60 km/h, continuous indication of vehicle position within the lane, and tracking relative lane-keeping accuracy over time to indicate fatigue.

Technologies for Road Departure Warnings

Like LDW systems, RDW systems provide lane tracking capability; however, these systems are designed more specifically to warn of roadway departure rather than the more generalized function of tracking lane deviation. One component that may be used in addition to lane position monitoring is CSW, which is based on digital maps and GPS (Bishop, 2005). When the vehicle is traveling too fast for an upcoming curve, the RDW system may present a haptic signal on the accelerator pedal in the form of resistance against pressure on the pedal. This signal encourages the driver to slow down. Other parameters that may be taken into account by the CSW system would include surface quality, street width, number of lanes, shoulders, visibility, and driving style of the driver.

The SafeTRAC system by AssistWare uses vision to measure lane drift and provides an audible alarm if the driver begins to depart the road or cross into another lane without activating the turn signal (Bishop, 2005). In addition, SafeTRAC can track the driver’s performance over time to provide an indication of the level of alertness or fatigue. In an FOT, this system was incorporated into a larger RDW system that combines a vision- and radar-based lateral drift warning system with a map-based CSW (UMTRI, 2003; Bishop, 2005, pp 106-107).

Summary

Although collision warning systems are relatively recent developments in automotive safety, many of these systems are based on technologies that have been proven in other applications. Radar is a proven technology for range finding in aviation and other applications. These systems are the most widely used technology in current CWSs. However, LIDAR technology also has been proven for making precise measurements in other applications, and manufacturers are overcoming the challenges associated with using LIDAR in the adverse environmental conditions found in CWS applications. Also, advances in image processing power and algorithms are making vision-based collision warning systems a viable and competitive option for CWS implementation. IR and ultrasonic sensing are inexpensive alternatives to radar, LIDAR, and vision; however, they typically offer limited range and poorer performance, and significant challenges need to be addressed for the successful use of these technologies in some applications. In any case, these technologies have been implemented in commercially available CWSs by a wide variety of manufacturers, who are overcoming many of the complex technical challenges associated with CWSs.

Tutorial 2: Activation and Operation of CWS Devices

Introduction

This tutorial provides information for CWS developers on the activation and operation of CWS devices. In the 1996 COMSIS Guidelines, this topic was addressed through separate subsections within five of the six primary technical chapters of the guidelines. For the current guidelines, this topic was deemed more suitable for inclusion as a single tutorial for two reasons: (1) the current guidelines are intended to focus only on those design topics having the highest impact on performance and safety and (2) a stand-alone tutorial was viewed as being the most logical method to communicate this information efficiently and cogently.

In addition to reviewing the recommendations for "activation and operation" provided in the 1996 COMSIS Guidelines, this tutorial includes a review of the suggestions and (limited) empirical findings related to this topic from more recent technical reports. Findings from these studies that are related to recommendations in the 1996 COMSIS Guidelines were categorized into the following topics:

- Application and Termination of Power
- Automatic Activation of Warnings
- Transient Manual Override of Warnings
- System Status Indicators
- Automatic Control of Auditory Displays
- Manual Operation of Controls

It should be noted that, for the most part, none of the current empirical studies specifically addressed many of the issues discussed here in a parametric fashion. Rather, the CWSs under investigation were designed with specific operational and design criteria in mind, and results related to the performance of those criteria were reported as an adjunct to the findings of the primary experiment. Most results related to activation and operation issues simply provided driver acceptance data on the options that had been implemented. Also, the empirical studies represented here are not intended to reflect a comprehensive review of all available research on the topic, but rather should provide information that reflects the direction and state of relevant research.

Application and Termination of Power

The application and termination of power refers to when and how the overall CWS should be activated in order to ensure that collision warnings are available during a potential collision threat. The 1996 COMSIS Guidelines recommend that power should be applied to the warning device during vehicle ignition, and the CWS should be placed in a standby mode at that time. In addition, an FCW should be activated when the vehicle is placed in forward gear.

Most research sources support the automatic activation of the CWS upon activating the ignition (e.g., see Pomerleau et al., 1999; Wilson et al., 1998). This capability precludes the need for the driver to remember to activate the system for each ignition cycle. However, Pomerleau et al.

(1999) recommend that the warning should be activated automatically only if the CWS master on-off switch is in the "on" position. This recommendation also implies that if the CWS master switch is in the "off" position, the warning should not be automatically activated during vehicle ignition. A more prudent strategy recommended by Kiefer et al. (1999) is to *always* reactivate the system at the beginning of the next ignition cycle. In any case, the CWS should provide a continuous visual indication to the driver as to whether or not the system is on and operating properly.

There is some disagreement among current sources regarding whether or not to allow drivers to turn off the CWS. On the one hand, a CWS that has been deactivated cannot provide an alarm during a true collision situation. On the other hand, if false- or nuisance-alarm rates are high under certain circumstances, then allowing drivers to disable the CWS may reduce driver annoyance and lead to a more satisfying experience with the CWS. Pomerleau et al. (1999) takes the latter point of view and recommends that a master on-off switch be provided to allow the driver to avoid the activation of false and nuisance alarms. In contrast, other sources (Wilson et al., 1998; Kiefer et al., 1999) recommend that drivers not be allowed to deactivate a FCW collision warning, which ensures that the warning will be active in a real potential crash situation. However, Kiefer et al. (1999) concede the potential need for deactivation capabilities if false- or nuisance-warning rates are high. It is our view that, unless false and nuisance alarms can be eliminated or severely curtailed, the provision of a master on-off switch is likely to be necessary in order to avoid excessive driver annoyance and dissatisfaction with the system.

Automatic Activation of Warnings

Automatic activation of warnings refers to conditions in which the warnings should be activated once power has been applied to the CWS. The 1996 COMSIS Guidelines suggest that maintaining all of the functions of the CWS in active mode at all times may lead to an increase in the frequency of false alarms. Therefore, they recommend activation of the CWS only during applicable driving conditions (e.g., the vehicle is placed in forward gear for FCW systems).

The results from other studies support this recommendation. In a field study by Talmadge, Chu, Eberhard, Jordan, and Moffa (2000), the LCW was disabled to prevent warnings when the vehicle was turning. The rationale behind disabling the alarms in this condition was that warnings that are presented while the driver is making a turn will be considered false alarms. Guidelines based on the results from these tests indicate that lane change CWSs should monitor the steering angle, forward gear position, and turn signal to determine if a turn is being made.

It is also important for the CWS to automatically reactivate when a system that was temporarily non-operational becomes capable of functioning properly again. Pomerleau et al. (1999) recommend that if the CWS is off-line due to a loss of signal integrity or other temporary condition, and then conditions arise that make it possible for the CWS to again function properly, that the CWS should automatically reactivate without explicit input from the driver. A brief auditory or haptic signal should announce the transition to the enabled state (Pomerleau et al., 1999).

Transient Manual Override of Warnings

The transient manual override of warnings refers to the situation in which a driver chooses to deliberately terminate a warning because it is a known nuisance alarm. In this case, the warning provides no information about hazards, while at the same time acting as a potential distraction. The rationale for providing transient manual override of warnings is that if drivers anticipate or understand that a warning is a nuisance alarm, then allowing them to disable it can reduce annoyance and distraction.

A likely example of a scenario in which known nuisance alarms may occur is when a driver deliberately activates a turn signal when there is an insufficient gap to change lanes, with the hope that other vehicles will adjust their spacing to permit a safe lane change. In this case, if the LCW system defines the ICW conditions based solely on turn-signal-activation rather than on intent to change lanes, then the system will present a nuisance ICW when the situation is not dangerous. Because this situation can occur relatively frequently in highway or city driving, an obtrusive ICW (e.g., auditory signal) can quickly become very annoying to drivers. Another less common example, involving RDW systems, is a required/planned lane departure in temporary work zones. Also, known nuisance alarms may occur in more general situations in which system detection sensitivity is too high, or if a hazard detection algorithm is ineffective at filtering out non-hazard signals in certain situations (e.g., continuous jersey barriers for LCW systems).

The 1996 COMSIS Guidelines recommend that transient manual override functions not disable visual warnings so that there is some degree of “back-up” functionality in case drivers fail to notice a potential hazard (e.g., a motorcycle in the driver’s blind spot). However, there are arguments for and against this recommendation and there are insufficient data to determine the best approach. For example, in the lane-change scenario described above, a flashing ICW on the mirror could potentially make the task of determining when there is adequate space to change lanes more difficult by providing an obtrusive competing visual signal when the driver is trying to use the mirror for a relatively difficult visual judgment task. On the other hand, if the LCW system is sufficiently accurate and reliable, drivers could forgo the judgment task and merely base their lane change decision on information from the ICW.

The 1996 COMSIS Guidelines also recommend that if known nuisance alarms are expected to be common, that transient manual override functions be provided for auditory and haptic warnings because of their obtrusive nature. Some of the situations in which the 1996 COMSIS Guidelines recommend providing manual override involve nuisance alarms arising predominantly from technical limitations of CWSs and their hazard detection algorithms. Recent progress in these areas has likely reduced the frequency of these situations, and correspondingly the need to directly address this situation with transient manual override capabilities.

Nevertheless, known deliberate nuisance alarms may be unavoidable in some situations, such as the examples described above, so manual override capabilities may be necessary in some form. Four different strategies for addressing known nuisance alarms are described in the list below and in Table 11-2. It is important to note that the discussion of these approaches is not based on data, and at this point there is no *empirical* basis for recommending one approach over any other.

Sensitivity Settings: This approach involves leaving it up to drivers to reduce nuisance alarms by using the standard sensitivity controls. It would apply to known nuisance alarms that arise from system implementation issues (e.g., high-sensitivity settings or poor filtering algorithms), but would not address situations that are initiated by the driver, such as the lane change example above.

Central Master Control Switch: This approach involves leaving it up to drivers to reduce known nuisance alarms by using a master control switch that fully enables or disables the entire system. This switch would not be specifically implemented to deal with known nuisance alarms, but for general deactivation of the system for a variety of reasons. Consequently, the corresponding control is likely to be located in a less convenient location that may hinder access during regular driving.

Easily Accessible Master Control Switch: This approach is the same as the central master control switch described above; however, it is implemented in a location that is easy to access during regular driving activities. An example would be a switch on the turn signal stalk for LCW systems.

Easily Accessible Temporary Override Switch: This approach is similar to the previous strategy in terms of the control location; however, it would function differently by only deactivating the system for a limited period of time (e.g., 2 minutes), rather than completely deactivating it.

Table 11-2. The advantages and disadvantages of different approaches to providing manual override capabilities for addressing known nuisance alarms

Implementation Strategy	Situation Addressed	Advantages	Disadvantages
Sensitivity Settings	Deficient detection algorithms/ system function	• No specific driver actions are required while driving.	• Does not address deliberate nuisance alarms. • May not eliminate all nuisance alarms.
Central Master control switch	Deliberate nuisance alarms	• Unlikely to be accidentally activated. • Can be implemented using a simple control with reduced "real estate" constraints.	• Drivers must interrupt their driving activities to operate the switch. • Drivers must remember to reengage the system.
Easily accessible Master control switch	Deliberate nuisance alarms	• Additional driver actions to operate the switch are minimally obtrusive. • May be complicated to implement/ space limitations.	• Drivers must remember to re-engage the system. • Drivers could accidentally disable the system without knowing it.
Easily accessible temporary override switch	Deliberate nuisance alarms	• Additional driver actions to operate the switch are minimally obtrusive. • The system would automatically reengage. • May be complicated to implement/ space limitations.	• It would require a separate control in addition to a "Master" control switch. • Drivers could accidentally disable the system but this would only last for a short period of time.

For more information related to the transient manual override of warnings, see guidelines in Chapter 8: *Lane Change Warning Systems*

System Status Indicators

Drivers need to know when the CWS is active, inactive, malfunctioning, or operating at a limited level of capability so that they know if they can expect to receive warnings in critical situations. The 1996 COMSIS Guidelines provide several recommendations that support this approach. Guidelines are included that provide for diagnostic testing with each ignition cycle, mode of operation after diagnostics (standby or failure mode), how to indicate failure in a multi-sensor system, type of display, and failsafe design. Recent research is consistent with the 1996 COMSIS Guidelines.

CWSs should have the ability to self-diagnose a failure (Talmadge et al., 2000; Campbell et al., 1996). This diagnosis should occur at the beginning of each ignition cycle. The CWS status visual display(s) should be presented such that drivers can clearly determine the functional status of the system when power is applied to the vehicle (Kiefer et al., 1999; Pomerleau et al., 1999).

CWSs are complex systems that can lose functionality for many reasons. According to Pomerleau et al. (1999) a CWS should be capable of determining and reporting the status of the system under the following conditions:

- The system fails its power-on self-test.
- The system is not working due to component failure or other cause during operation.
- The system detects conditions that have rendered it ineffective (e.g., insufficient road markings to track, poor atmospheric conditions, etc.).

It is critical that under these conditions the CWS must fail in such a way that it does not create a hazardous condition. The CWS should be able to recognize situations where poor environmental conditions result in degraded system performance and, upon recognizing the condition, the CWS should discontinue operation and report the situation to the driver. Also, all warning displays should be explicitly suppressed during the failure mode.

In addition to system diagnostics guidelines, COMSIS (1996) provides recommendations regarding the initialization of CWS operational parameters. Two recommendations related to the 1996 COMSIS Guidelines deal with default settings and prior settings. Talmadge et al. (2000) recommends that initial factory settings should be set to the most conservative values in lane change CWSs, but that drivers should have the capability to adjust these settings within limits that maintain effective CWS performance. Guidelines by the ISO (ISO Technical Committee, 2001) recommend that if the system retains the last selected setting after the CWS is turned off, information about the setting should be provided when the system is again activated. This way, there is no ambiguity about the value of system settings upon activation of the CWS.

Finally, the 1996 COMSIS Guidelines provide some guidance with regard to the characteristics of effective warning-system status indicators. These guidelines are fairly general and indicate that the CWS should provide status indicators, that each warning device should have its own status indicator, and that status displays should be discriminable from warning displays. In addition, status displays should not distract from warning displays.

Several recommendations based on empirical studies have been developed that describe various characteristics of status indicators that effectively inform the driver of the status of the CWS without being distracting. Although recommendations from individual sources refer to the specific type of CWS studied, the concepts and applications should apply more generally to all collision warnings.

One of the primary characteristics of these indicators is that they be communicated visually. Moreover, this visual display should continuously indicate to the driver that the system is on and operating properly (Pomerleau et al., 1999). If the CWS malfunctions or becomes limited in capability (i.e., the system loses part but not all of its functionality), the visual indicator should clearly indicate the malfunction, and this information should be continuously displayed (Kiefer et al., 1999). Also, whenever possible, icons that are used to notify drivers of a malfunction or system-limiting condition should consist of industry standard symbols (ISO Technical Committee, 2001).

In addition to the visual display, a brief, momentary auditory tone should announce the transition of the status indicator to draw the attention of the driver to the visual status display. The tone used for this purpose should be distinctly different from auditory displays used in CWSs. Low priority signals such as earcons and speech messages are appropriate for announcing the transition of status indicators. However, the use of repetitive auditory signals should be avoided, because repetition of auditory signals may be perceived as annoying (see guidelines on page 3-4). In any case, the supplementary signal should not be distracting or disturbing to the driver.

For more information related to the use of system status indicators, see Chapter 3. *Auditory Warnings* and Chapter 4. *Visual Warnings*.

Automatic Control of Auditory Displays

Automatic controls of auditory displays refers to the adaptive control of various CWSs and in-vehicle system devices and parameters in order to maximize the effectiveness of auditory warnings. The 1996 COMSIS Guidelines recommend the adaptive adjustment of auditory displays in order to ensure that auditory warnings are presented at adequate levels above the MT. This approach may be acceptable as long as the final display intensity does not exceed 90 dB in passenger vehicles. The 1996 COMSIS Guidelines also recommend that ancillary auditory signals (e.g., radio, navigation systems with speech displays, etc.) be muted when collision warnings are displayed (see guidelines on pages 2-5 and 3-6).

For more information related to the automatic control of auditory displays, see Chapter 2. *General Guidelines for CWS Warning Design* and Chapter 3. *Auditory Warnings*.

Manual Operation of Controls

Manual operation of controls refers to those functions that should be adjustable by the driver and issues related to manual adjustments of the CWS controls. COMSIS (1996) provides several guidelines for manual adjustment of auditory and visual signal intensity and audibility/visibility limits of displays under various conditions.

Current research sources are consistent with the 1996 COMSIS Guidelines regarding adjustment of the intensity of visual displays in order to maximize visibility of the display in varying levels of ambient light within the vehicle (e.g., see Kiefer et al., 1999). During daytime usage, the display must provide enough luminance to be visible, particularly in bright sunlight and other conditions where glare from high levels of ambient light can cause a decrease in overall display contrast (see guidelines on page 4-8). Also, the driver should be able to reduce the display level at nighttime to reduce the amount of discomfort and distraction caused by glare from the display. However, the control should be designed such that the driver cannot dim the visual alert display to a level that is invisible, whatever the ambient conditions.

Pomerleau et al. (1999) also recommend providing the ability to adjust the signal intensity of all CWS displays, regardless of modality. The minimum adjustable signal intensity will depend on the modality and characteristics of the signal. Nonetheless, the minimum intensity level should be no lower than that which is detectable by 95 percent of the population under normal in-cab conditions.

Recommendations regarding the adjustment of detector sensitivity, headway, and TTC and the requirements for their associated controls are presented in the 1996 COMSIS Guidelines. Current sources provide additional information related to the characteristics of controls for these adjustments. When sensitivity or timing adjustment is made available, the associated control and the criterion settings should be clearly labeled so that the driver can easily comprehend the control (Kiefer et al., 1999). Also, a minimum warning zone should be designated below which drivers are not allowed to reduce sensitivity (see guidelines on page 7-2). The control type should be appropriate for the type of adjustment required, and the control movements and labeling should be consistent with population stereotypes for control/display relationships. For example, a rotary control, slide, or thumbwheel control is recommended for adjusting crash alert timing or sensitivity. Manual adjustment should not distract the driver from the driving task (see also Pomerleau et al., 1999; Pierowicz, Jocoy, Lloyd, Bittner and Pirson, 2000; and the guideline on page 6-2).

Drivers may prefer to adjust the headway and TTC settings in order to accommodate personal driving styles and prevailing driving conditions. Also, the ability to adjust these parameters can help to reduce the rate of false and nuisance alarms. Kiefer et al. (1999) provide an algorithm for determining “too early” and “too late” thresholds for FCW timing (see the guideline on page 7-2). In addition, Pomerleau et al. (1999) provide recommendations for early and late timings for an RDW. Adjustment of warning criterion outside of the early or late threshold should be avoided in order to prevent unintentionally compromising system effectiveness (see also Talmadge et al., 2000).

The ability to control the warning sensitivity in a FCW was successfully demonstrated in a field test in General Motors Corporation (2005). In this test, drivers could adjust the sensitivity of the cautionary alert to a lowest setting that suppressed cautionary warnings altogether. However, drivers tended not to disable the cautionary warning in spite of experiencing high CCW rates while driving.

Also, drivers in this study used the full range of six FCW sensitivity settings, adjusting the sensitivity two or three times per hour of driving on average. Older drivers generally preferred higher sensitivity settings, while younger drivers preferred lower settings. In addition, males were more active in making sensitivity adjustments than females.

In summary, drivers should be given some control over display and system sensitivity settings, especially if false and nuisance alarms are a problem. However, this control should be restricted to setting ranges that preserve the effectiveness of system operation.

For more information related to the operation of controls, see Chapter 6. *Controls Used in CWS Devices.*

Tutorial 3: Factors to Consider in Designing CWS DVIs for Large Vehicles

Large vehicles present unique requirements and challenges in the design of CWS DVIs. Heavy trucks and transit buses share several common differences from passenger vehicles, but there are also many factors that are unique to each vehicle type. Unfortunately, limited research has directly addressed the appropriate features of CWS DVIs for heavy vehicles, resulting in relatively limited guidance being provided in Chapter 10 and the present guidelines. This tutorial reviews four pertinent topics relevant to heavy trucks and transit bus CWS DVI design: vehicle characteristics; operational considerations; crash data; and driver tasks and workload. The tutorial is being provided to augment the limited set of CWS DVI guidelines and provide general information that may be useful to designers in developing preliminary CWS DVI concepts. The following discussion is limited to tractor semi-trailer heavy trucks and transit buses. Large vehicle types that are not explicitly addressed in this discussion include single unit trucks, coach buses, and school buses.

Vehicle Characteristics

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 axels and a maximum weight of 80,000 to 99,000 lbs. Figure 11-1 presents two common heavy-truck configurations. The single trailer on the left 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.

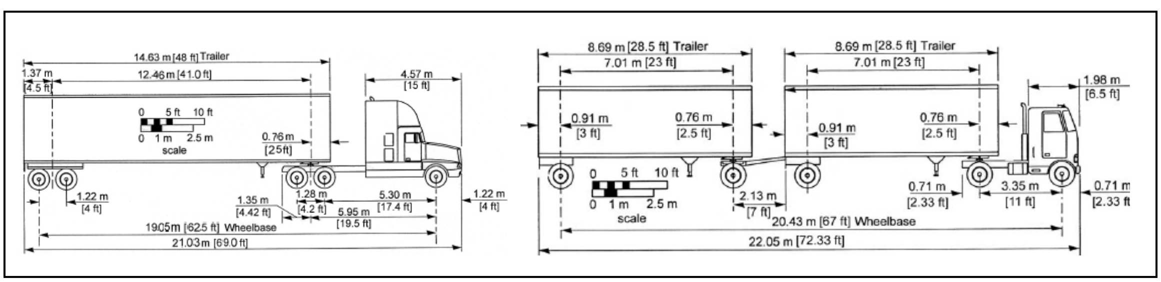

Figure 11-1. Typical tractor-semitrailer configurations (from AASHTO, 2004).

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 11-2.

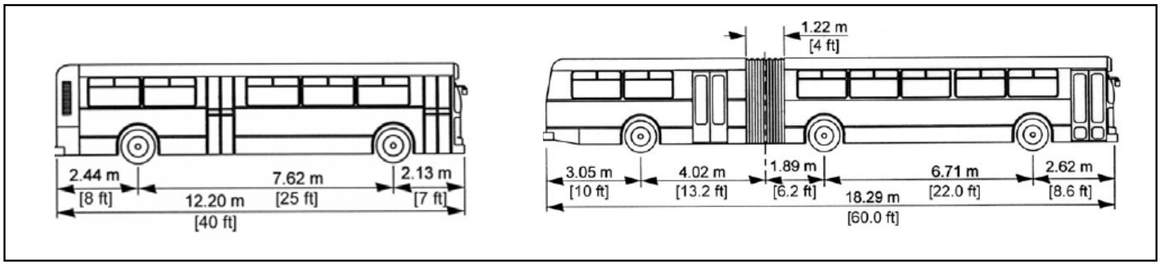

Figure 11-2. Typical city transit bus configurations (from AASHTO, 2004)

Stopping Distances

The stopping distances of large vehicles relative to that of passenger vehicles is a primary factor in establishing FCW timing parameters. Stopping distance is the distance needed to stop a vehicle from the time that brake application begins. It does not take into account the driver's perception-response time. FMVSS No. 121 (49 CFR 571.121) establishes the minimum stopping distances for loaded and unloaded buses and loaded truck tractors tested with an unbraked control trailer. These stopping distances are depicted graphically in Figure 11-3 along with regulated passenger vehicle stopping distances (49 CFR 571.135). As can be seen from a review of this figure, regulated bus stopping distances are halfway between those of passenger vehicles and those of loaded truck tractors with unbraked control trailers for all vehicle speeds.

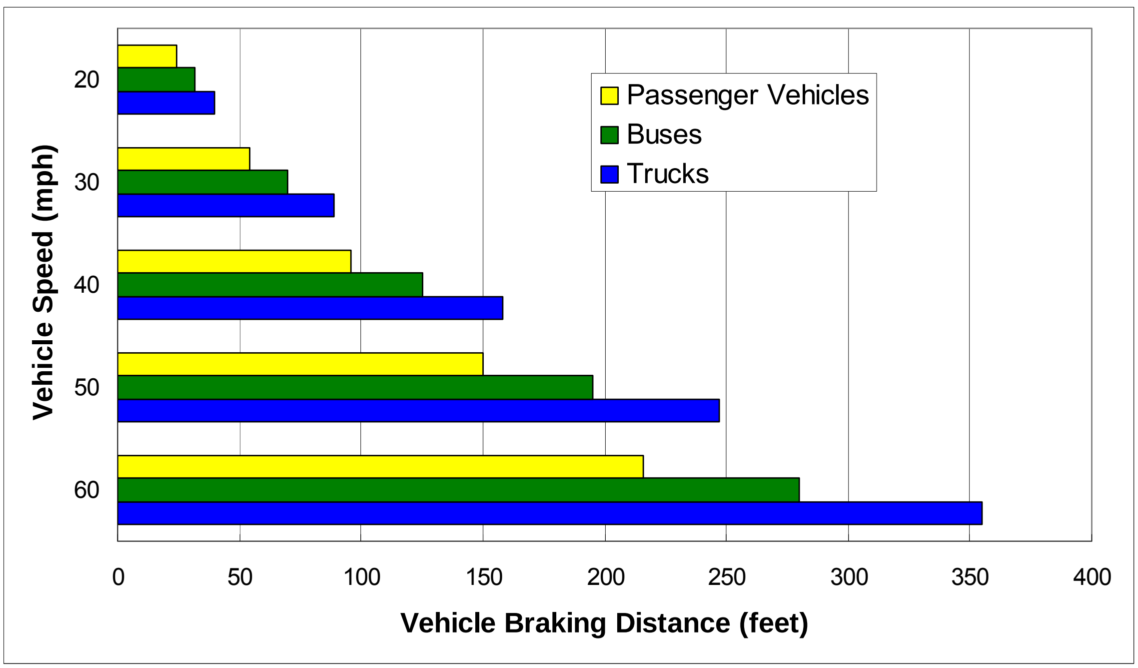

Figure 11-3. Stopping distances for passenger vehicles, loaded and unloaded buses, and loaded truck tractors with unbraked control trailers

NHTSA has indicated that the difference in the regulated stopping distance between heavy trucks and passenger vehicles represents a significant safety issue and has recently been conducting studies to determine if it would be technically feasible to reduce the regulated stopping distances of heavy trucks by 30 percent. This reduction in stopping distance would result in stopping distances for a loaded truck tractor with an unbraked control trailer that would decrease from 299 to 209 feet at 55 mph and from 355 to 249 feet at 60 mph (Federal Motor Vehicle Safety Standards: Air Brake Systems, 2005). As part of this effort, the stopping distances of four production truck tractors with various brake configurations were recently tested (Ashley, Dunn, & Hoover, 2004). Mean stopping distances (across six tests for each vehicle) from 60 mph on a dry, level roadway were between 241 feet and 317 feet, with only one of the four vehicles consistently stopping within the contemplated reduced stopping distance of 249 feet. For the purposes of the present review, it will be assumed that vehicle stopping distances are consistent with current regulations, as depicted in Figure 11-3.

Drivers' Working Areas

One starting point in reviewing large-vehicle drivers' working areas is to consider the general layout of seating and controls. Figure 11-4A presents a rendering of a current-model Kenworth truck cab and Figure 11-4B is a photograph of a transit bus operator's working area in a representative transit bus layout. 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.

Figure 11-4A. View inside a recent model Kenworth cab (accessed March 2006 from www.kenworth.com)

Figure 11-4B. View of Nova Bus transit bus driver's area (accessed May 2006 from www.novabus.com)

Visual Environments: The heavy-truck cab visual environment presents special challenges to the heavy-truck driver who must continually monitor the roadway and traffic while controlling the truck on the road. 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 a heavy truck. Because of the location of the driver and configuration of the tractor and trailer, heavy-truck blind spots are not symmetrical on either side of the vehicle, with the driver's right side having more extensive unobservable areas. Blind spots and some of the dangerous locations around a typical heavy truck are depicted in Figure 11-5. 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 (1995) found that fender-mounted mirrors provided blind spot coverage superior to any other side object detection system that they tested.

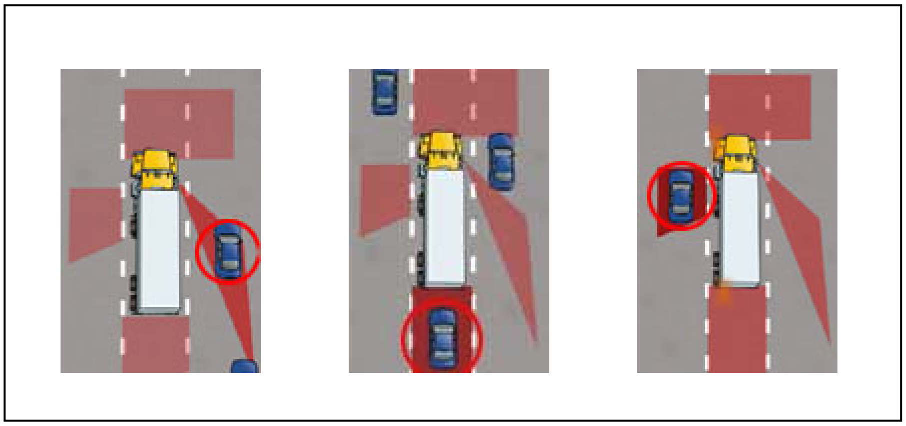

Figure 11-5. Depiction of heavy-truck blind spots
(adapted from Transports Quebec, 2006)

Transit bus drivers must also deal with the challenge of blind spots in their working environment. Figure 11-6 depicts the blind spots identified by Thorpe, Duggins, McNeil, and Mertz (2002) during their specification of transit bus SCW system requirements. It should be noted that the general locations of the depicted blind spots in Figure 11-6 are influenced by dash height, fare box location, and mirror location. Transit bus operators work in a highly variable visual environment that is influenced by time-of-day, roadway lighting fixtures, and passenger lighting. Illumination inside transit buses during nighttime operations has led transit bus operators to request control of CWS display illumination levels and the ability to turn-off visual displays in one requirements study (Wang et al., 2003).

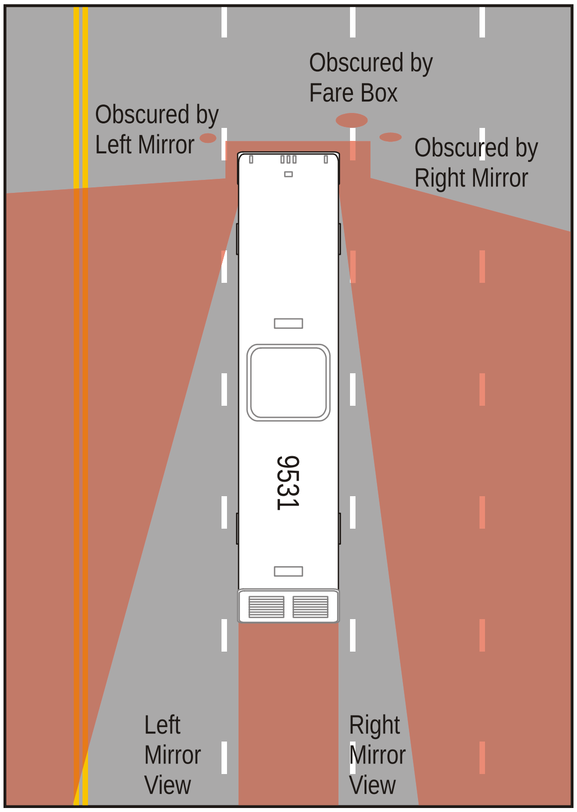

Figure 11-6. Depiction of typical transit bus blind spots
(adapted from Thorpe, Duggins, McNeil, and Mertz, 2002)

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.

Auditory Environments: Robinson, Casali, and Lee (1997) provide a comprehensive, though somewhat dated, review of heavy-vehicle driver hearing requirements and truck cab noise levels. In reviewing earlier studies, they conclude that truck cab noise dramatically decreased from the 1970s to the 1990s. The researchers then measured noise levels in 10 “fairly high-mileage” 1990s trucks under actual operational conditions and found on-road noise levels averaging 89 dBA. In discussing the implications of truck cab noise for in-cab warning signal design, Robinson et al. suggested the use of noise-sensing circuits that adjust alarm output levels as the truck cab noise level changes, thereby maintaining a desired signal-to-noise ratio.

Sources of noise in transit buses include the vehicle engine, air brakes, pneumatic doors, coin sorter, passengers, and surrounding traffic noise. The present authors are not aware of a systematic study of the auditory environment in the transit bus operator’s working area. However, Reinach and Everson (2001a) did identify relatively high and variable levels of ambient noise in transit buses as a consideration in CWS signal design.

Haptic/Tactile Environments: The truck cab haptic/tactile environment is of interest in the present review because the coding of heavy-truck CWS warnings might potentially employ some form of haptic or tactile coding. Empirical studies of the haptic/tactile cab environment were not uncovered during the present literature search. However, Jiang, Streit, and El-Gindy (2001) reviewed heavy-truck ride comfort research and cab vibration estimation simulation approaches. These authors note that vehicle suspension is a very important factor in cab vibration. However, heavy-truck handling and rollover characteristics are the primary concerns in designing suspensions; leaving the cab suspension, seat suspension, and the seat cushion as the components that can be modified to reduce driver vibration.

Reinach and Everson (2001a, 2001b) cite conditions of high vibration in transit buses in recommending that transit bus CWS displays must be capable of being presented, attended to, and understood under high-vibration conditions. These authors specifically highlight the likely masking of foot pedal and steering wheel vibration coding onboard transit buses. 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." One operator commented, "After eight hours, I don't have any idea what's going on down there."

Operational Considerations

Three topics related to heavy-truck and transit bus operations relevant to CWS DVI design are the roadway environment, driver characteristics, and reactions by large-vehicle drivers to early tests of CWS devises. Each of these topics is briefly reviewed below.

Roadway Environments

Kiger et al. (1992) surveyed 55 heavy truck drivers to determine the relative perceived importance to safety of a range of driving condition factors. Table 11-3 presents the scaled relative importance to safety of these factors as judged by the sampled drivers. As can be seen in the table, each factor was scaled as being approximately twice as important as the next-most-important factor with the order of relative importance being: road traction, visibility, traffic density, roadway division, and lighting.

Table 11-3. 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). A recent analysis of transit bus CWS requirements noted that "Transit operators often encounter risky behavior on the part of nearby drivers and pedestrians. For example, it is not uncommon for vehicles to speed past a bus on the left and then cut in front, only to immediately turn right" (University of California [UC] PATH and Carnegie Mellon University Robotics Institute [CMURI], 2004).

A field study of selected California transit bus speeds yielded the data summarized in Figure 11-7 (Wang et al., 2003). Review of this figure reveals that the transit buses included in this analysis operate at a range of speeds, reflecting the various activities of picking-up passengers at relatively slow speeds, traversing busy urban streets, traveling on arterials, and some limited higher speed highway driving.

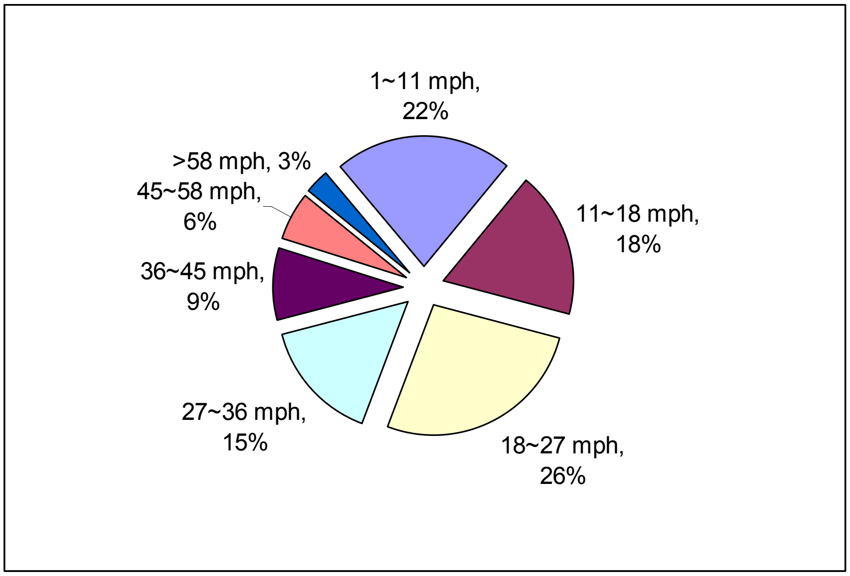

Figure 11-7. Transit bus vehicle speeds (adapted from Wang et al., 2003)

Driver Characteristics

Both heavy-truck and transit bus drivers are required to meet Federal Motor Carrier Safety Administration (FMCSA) requirements for obtaining and maintaining a Class A (any combination of vehicles with a Gross Vehicle Weight Rating [GVWR] of 26,001 or more pounds) or Class B (any single vehicle with a GVWR of 26,001 or more pounds) commercial driver's license (CDL). Drivers who operate special types of large vehicles also need to pass additional tests to obtain CDL endorsements for: double/triple trailers, passenger, tank vehicle, hazardous material, or combination of tank vehicle and hazardous material.

Physical requirements for obtaining a CDL include 20/40 corrected vision, a 70-degree field of vision in each eye, and normal color vision. Commercial drivers are given a hearing test that requires them to hear a forced whisper in one ear at not less than 5 feet, with or without a hearing aid. Drivers must have normal blood pressure and have normal use of their arms and legs.

Heavy-truck driver training is quite variable. There are limited Federal standards for training, with only four topics requiring approximately 10 hours identified in current FMCSA training standards. Comprehensive training programs are available and the Professional Truck Driver Institute certifies courses, which must 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. However, many of the larger carriers do not require driver training, but rather require minimum driving experience levels (e.g., two years) and a "clean" driving record (Staplin, Lococo, Decina, & Bergoffen, 2004).

Most transit bus systems provide their driver trainees with two to eight weeks of classroom and behind-the-wheel instruction. Classroom training typically addresses Department of Transportation and transit authority work rules and safety regulations, State and municipal driving regulations, and safe driving practices. Transit bus driver trainees also receive instruction in reading schedules, determining fares, keeping records, and dealing courteously with passengers. Behind-the-wheel training typically begins on a course where turning, backing up, and driving in narrow lanes is practiced. On-road training will follow course training and typically progresses from light to congested traffic conditions, followed by supervised driving on scheduled revenue routes.

Driver Reactions to Early Tests of CWS Components

Two recently completed projects have included on-road assessments of CWS technologies in heavy trucks. Dinges, Maislin, Krueger, Brewster, and Carroll (2005) recently completed a pilot study of heavy-truck fatigue management technologies that included the SafeTRAC lane departure warning system. Battelle (2004) also recently completed the Volvo Intelligent Vehicle Initiative (IVI) field operational test (FOT) that included assessments of the Eaton VORAD side and forward collision warning systems. On the whole, the findings from these earlier studies indicate that heavy-truck drivers exposed to these CWS technologies had mixed opinions regarding their benefits and value. Quite a few drivers were willing to adopt these technologies; while other drivers objected to the lack of display adjustment and/or had difficulty interpreting displayed information.

The recently-completed pilot study of heavy truck fatigue management technologies (Dinges et al., 2005) reported that the SafeTRAC lane departure system received only modestly favorable ratings. In reviewing these findings, Dinges and his colleagues noted that one common comment by drivers was that the SafeTRAC volume control on the auditory alarm was set too high and not under their control, which was a feature of the pilot study protocol rather than the technology. It was concluded by these researchers that this negative reaction to the auditory alarm might have reduced overall driver acceptance of the system (Dinges et al.).

The recently-completed Volvo IVI field operational test provides some information regarding drivers' reactions to the Eaton VORAD side and forward collision warning system interfaces (Battelle, 2004). Much of the driver feedback was quite favorable, although some specific issues in understanding some warning information was obtained. Following are some selected findings. Eighty-seven percent of drivers reported that the VORAD warning lights were "always" easy to see. Sixty-four percent of drivers indicated that the VORAD audible alerts were "always" easy to hear. Most drivers said visual (78%) and auditory (84%) warnings “rarely” or “never” drew their attention away from their driving tasks. Sixty-two percent of drivers indicated that they could “always” distinguish between the forward and side warnings. Of those drivers with other “warning or beeping” systems in their vehicles, 79 percent indicated that they could always distinguish between the auditory warning of those other systems and the VORAD system. Finally, many drivers did not understand the intended meaning of ICW, CCW, and advisory warning levels. Drivers’ responses to questions regarding the appropriate reaction to an advisory, cautionary, or imminent warning were nearly identical in all cases.

UC PATH and CMURI (2004) reported the results of an 11-month pilot test of two transit buses equipped with prototype FCW and 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 were 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.

Crash Data

Overall crash and fatality rates for trucks, buses, and passenger vehicles are somewhat difficult to compare. The challenge is to choose between statistics based on vehicle miles or passenger miles for such comparisons. The following discussions address the distribution of crash types for heavy trucks and transit buses separately.

Heavy Truck Crash Data

The heavy truck driver has the demanding task of maintaining safe control of his/her vehicle while maintaining vigilance and awareness of other vehicles. Highway fatality data suggest that the defensive driving requirements are the most demanding, since the majority of fatal accidents involving trucks have been attributed to passenger vehicle driver actions. FMCSA recently provided a preview of results from their ongoing Large Truck Crash Causation Study (LTCCS) (FMCSA, March 2006). This study is an in-depth investigation and analysis of 967 heavy-truck crashes that occurred over a 33-month period between 2001 and 2003 at 24 sites and involved at least one fatality or at least one incapacitating on non-incapacitating but evident injury. This sample was used to calculate national estimates of similar accidents. A first, noteworthy finding reported by FMCSA in this report is that the “critical reason” for crashes that involved a heavy truck and passenger vehicle was assigned to the passenger vehicle 56 percent of the time and the heavy truck 44 percent of the time.

Table 11-4 presents the estimated national percentage of heavy truck crash types based on the LTCCS sample distribution. Review of the first three most prevalent crash types supports the value of FCW, LDW, and SCW systems for the heavy truck CWSs, as these three directly-related crash types account for over 51 percent of all estimated crashes.

Table 11-4. Estimated percentage of heavy trucks in crashes by crash type (adapted from FMCSA, 2006)

Type	Percent**
Rear End	23.1%
Ran off Road/Out of Lane	17.8%
Side Swipe, Same Direction	10.3%
Rollover	8.9%
Turning across Path/into Path	8.0%
Intersecting Vehicles, Straight Paths	5.8%
Side Swipe, Opposite Direction	4.6%
Head-on	3.0%
Hit Object in Road	1.8%
No Impact (fire, jackknife, other,)	0.9%
Backing into Other Vehicle	0.3%
Other Crash Type	15.5%
Total Trucks	100.0%

In all of the 967 crashes included in the LTCCS, a "critical reason" was assigned to a truck (rather than another vehicle) in 55 percent of crashes, with the remaining 45 percent being assigned to the other vehicle. A single "critical event" was assigned to each of these crashes, providing a valuable tool for considering the type of vehicle, environment, and driver factors that contribute most prevalently to heavy truck crashes. Table 11-5 presents these findings, which indicate that driver-related critical reasons account for over 87 percent of these crashes (48% of all crashes), with vehicle conditions and the environment accounting for the remaining 13 percent of these crashes (7% of all crashes). Review of this table reveals that "Driver Decision" was assigned the critical reason in an estimated 38 percent of such crashes. Here, Driver Decision refers to situations such as driving too fast for conditions, misjudging the speed of other vehicles, following other vehicles too closely, or making false assumptions about other drivers' actions. The second-most frequent critical reason was "Driver Recognition," which refers to the driver not recognizing the situation by not paying proper attention, being distracted by something inside or outside the vehicle, or failing to adequately observe the situation. Note that many of the situations associated with critical events involving driver decision or recognition could trigger a CWS heavy-truck alert.

Table 11-5. Estimated percentages of heavy trucks in all crashes by critical reasons (adapted from FMCSA, 2006)

Critical Reasons	Percent of Crashes Assigned to Heavy Trucks
Driver Decision	38.0%
Driver Recognition	28.4%
Driver Non-Performance	11.6%
Vehicle	10.1%
Driver Performance	9.2%
Environment	2.3%
Unknown	0.3%
Total Assigned to Heavy Truck	100.0%

Transit Bus Crash Data

Thorpe et al. (2002) contend that "The kinds of accidents encountered by transit buses are much different [than passenger cars]: the objects struck are likely to be smaller (pedestrians, lamp posts, cyclists); the normal operating environment is much more cluttered; and the boundary between a safe and a dangerous situation is much more difficult to discriminate." NHTSA Traffic Safety Facts 2004 provide a general characterization of the relationship of initial point of impact and crash severity for commercial buses (which includes transit buses, intercity buses, and school buses), as depicted in Figure 11-8. Review of this figure suggests that forward collisions are the overwhelming concern in fatal crashes, that both forward and rear collisions account for the majority of injury crashes, and all points of impact have comparable levels of involvement in property damage crashes.

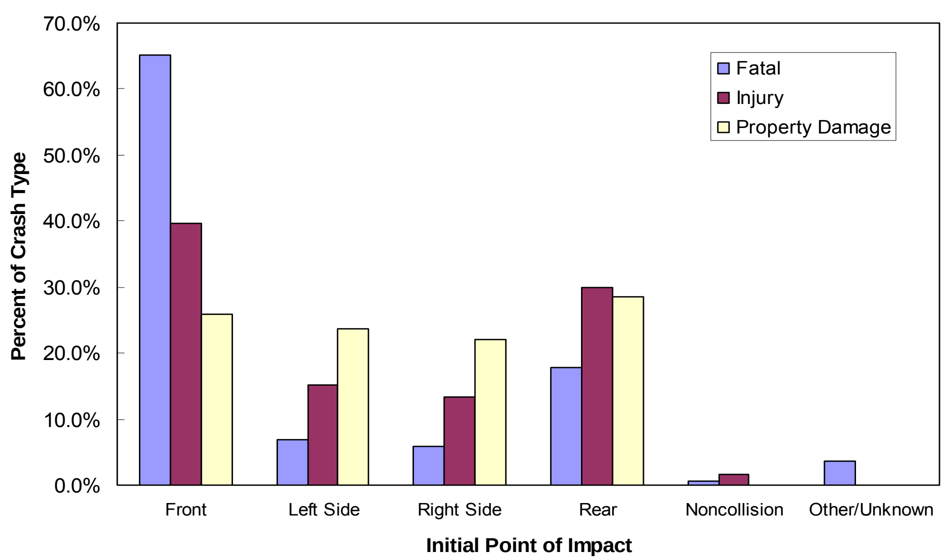

Figure 11-8. Bus crash initial point of impact (adapted from Wang et al., 2003)

Burke, Brewer, and Zirker (1999) analyzed NHTSA General Estimate System (GES) bus crash data from 1994-1996 (which probably included intercity coach bus crash data as well as transit bus crash data). The distribution of crash categories identified in this analysis provided strong support for the development of SCW systems for buses, with almost 36 percent of all crashes involving a lane change or merge (Table 11-6). These authors' review of bus crash data led them to recommend that future CWS efforts be focused on four systems: Lane Change/Merge, Rear Impact, Forward Collision, and Tight Maneuvering and Precision Docking.

Table 11-6. Distribution of bus crash categories
(adapted from Burke, Brewer, and Zirker, 1999)

Crash Category	Percentage of All Crashes
Lane Change/Merge	35.97
Rear End	21.53
Intersection	17.80
Parked Object	9.00
Backing Up	3.27
Other	2.93
Pedestrian/Animal/Object	2.90
Single Road Departure	2.53
Opposite Direction	2.17
Unknown	1.37
Non-incident	.57
Total	**100.04**

Driver Tasks and Workload

Two related topics that are central to CWS DVI design are large vehicle driver tasks and the driver workload associated with these tasks. Each of these topics is reviewed separately for heavy truck and transit bus operations in this final section of this tutorial.

Heavy Truck Driver Tasks and Workload

Turanski and Tijerina (1992) conducted an extensive study of heavy truck driver tasks and workload with the objective of providing methods and preliminary results regarding the implications of introducing advanced technologies into the heavy truck cab. Early during that project, a set of driving tasks was identified, a subset of which were selected for the focus of workload assessment. The standard and non-standard driving tasks identified by Turanski and Tijerina are presented in Table 11-7, which is organized into the task categories of basic driving tasks, lane changes and passing/overtaking, turns and curves, intersections and crossings, non-standard (emergency) driving, and parking and related activities. Tasks with an asterisk were identified as those most relevant to in-cab device interaction.

Table 11-7. Standard and nonstandard driving tasks (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

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 tire(s)
Recover from tire failure, other tire(s)
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)

Parking and Related Activities
Park tractor-trailer
Back-up

As a continuation of earlier research, Tijerina et al. (1995) conducted an on-the-road study of driver glance behavior with 30 professional truck driver participants who each drove either a 1992 Volvo/White GMC conventional tractor with sleeper compartment or a 1993 Fruehauf (both of which hauled a dry freight van semi-trailer loaded with ballast to bring gross vehicle weight to 76,300 pounds) on a fixed route of 285 miles that was divided between daytime and nighttime driving. Table 11-8 summarizes the obtained driver glance times, which are divided by road type since analyses indicated that observed glance times differed significantly across road type for each of these glance measures.

Table 11-8. Driver glance times of observed tasks
(adapted from Tijerina et al., 1995)

Glance Measure	Urban Freeway	Rural Freeway	Rural Road
Left Mirror avg. duration (sec)	1.00	1.01	0.87
Right Mirror avg. duration (sec)	0.96	1.05	0.90
Mean Mirror glance duration (sec)	1.02	1.04	0.89
Instrument Panel avg. duration (sec)	0.84	0.93	0.76
Off-road avg. duration (sec)	0.97	1.01	0.87
On-road avg. duration (sec)	2.64	2.43	5.27
Proportion of Time Spent	0.083	0.092	0.047

As part of their on-the-road study of heavy truck driver glance behavior, Tijerina et al. (1995) had a ride-along experimenter ask the driver participant to perform several tasks found in normal, everyday truck driving at a time when headway from another vehicle was a minimum of 200 feet. Table 11-9 summarizes the video data analyzed during performance of seven of these requested tasks. The resulting measures provide a good index of the individual and combined amount of time that heavy truck drivers take their eyes off the road to perform these common tasks which, in turn, is useful in estimating overall perception times in response to roadway hazards.

Table 11-9. Driver glance times of directed tasks
(adapted from Tijerina et al., 1995)

Requested Task	Mean Device Glance Duration	Mean No. of Glances to Device	Average Time Off Road	Average Road Glance Duration During Task
Adjust Radio Volume	0.76	1.10	0.90	1.65
Right Mirror Detect	1.37	1.05	1.43	0.64
Read Air Pressure	1.57	1.16	1.80	0.61
Tune Radio	1.22	5.61	6.75	0.89
Tune CB	0.95	3.23	2.99	1.04
Read Clock	1.20	1.03	1.23	0.66
Left Mirror Detect	1.21	1.05	1.27	0.69

In summarizing their visual allocation data analyses, Tijerina et al. (1995) noted that drivers adapted well to workload induced by the environmental factors of road type, lighting, and traffic (car following). Drivers allocated 90 percent of their visual resources to road sampling for nighttime two-lane highways versus 70 to 75 percent for daytime four-lane rural expressways. When required to sample for information off the roadway (e.g., mirrors and gauges) drivers limited their average time off the roadway to between 0.85 and 1.03 seconds. Drivers showed a tendency to quicken glances off the roadway for two-lane highways versus the freeways. Conversely, mean "on-road" glance durations were longer for two-lane roads and night operations.

The workload demands of heavy-truck driving are typically viewed as higher than those for passenger vehicles, due to more complex vehicle control operations (steering, shifting, and braking). Heavy-truck driver opinion appears to be consistent with this general view. Kiger et al. (1992) also 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 has the lowest workload, while an "8" means the task has the highest workload. Table 11-10 presents the mean rank orders (n=21). 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 11-10. Mean rated workload of common driving tasks
(adapted from Kiger et al., 1992)

Task	Mean	Std. Dev.
Check 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
Drive 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 the factors that they viewed as affecting workload levels. These researchers found that operational and driving environment factors combined to induce stress and workload. They concluded that it would be essential to control these factors in any studies attempting to assess driver workload. Tijerina and his colleagues also anticipated the implications of these factors in an assessment of in-vehicle safety systems, noting that an evaluation of such systems would best be conducted under demanding conditions, including inclement weather, congested traffic, and roadway construction zones (Tijerina et al., 1995).

Transit Bus Driver Tasks and Workload

For the purposes of the present discussion, transit bus driver duties and activities can generally be divided into those performed during periods when the bus is being driven and when it is parked or waiting for passengers. Transit bus driver duties that are primarily performed when they are not driving the bus or when the bus is stopped include the initial safety check of the vehicle; managing fares collection, tickets, and transfers; updating logs and record books; and providing passengers with route and procedure information. Activities performed while the driver is preparing to enter traffic or driving include merging into traffic, negotiating streets with limited side clearance, negotiating busy intersections, stopping and 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 under tight time constraints.

During initial stages of a project conducted to redesign the work areas of transit buses manufactured and operated in Germany, Gobel, Springer, and Scherff (1998) conducted task analyses and assessed the stress and workload of transit bus operators performing their duties. These researchers observed eight transit bus operators each complete a transit driving sequence on one of four bus types in one of four German cities.

Gobel et al. (1998) also collected and analyzed driver gaze data using a head-mounted device with 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 11-11.

Table 11-11. Distribution of transit bus driver gaze times
(adapted from Gobel, Springer, and Scherff, 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

Gobel et al. (1998) obtained gaze frequency and duration measures at a relatively fine level of activity resolution (see Table 11-12). However, the gaze times were not analyzed separately for driving or non-driving periods or for different driving conditions and thus provide very general indications of transit bus operator gaze frequency and duration. Review of those gaze directions that were most likely occurring during driving (i.e., those excluding inside mirror, customer, cash box, and money) present consistent mean durations ranging between 0.55 and 0.75 seconds. This suggests a general driving strategy of continual scanning of multiple locations without extended gaze durations on the forward roadway. If these gaze times are valid, they represent a pattern that is quite distinct from the heavy-truck gaze times obtained by Tijerina et al. (1995), where average forward roadway gaze durations were between 2.4 and 5.2 seconds, depending on the type of roadway. Assuming that these gaze times are generally representative of transit bus operator behavior, they point to the different nature of hazards in the transit bus environment. In the heavy truck environment where most travel is at freeway speeds, drivers must focus their attention for relatively long periods of time on the forward roadway in order to obtain adequate awareness of the traffic situation and must limit the period of their gazes away from the forward roadway in order ensure perception of emerging hazards. In contrast, in the transit bus environment where the majority of driving is at urban roadway speeds, the data in Table 11-12 suggest that frequent but brief gazes to the forward roadway suffice for the identification of emerging hazards; and scanning to either side of the bus at somewhat lower frequencies, but for equal periods of time, appears to be required.

Table 11-12. Distribution of transit bus driver gaze frequencies and durations
(estimated from Gobel, Springer, and Scherff, 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

Gobel et al. (1998) also obtained heart rate frequency and heart rate variability measures as indices of driver strain. The researchers note that "High strain occurs particularly during customer service tasks and just before leaving bus stops. This may be explained by the time pressure because this is the only occasion for the driver to gain time. It may be further caused by the change in body posture, which involves turning to the cashier desk on the right side, and also the illegible and coded prints on the tickets. Increased strain also occurs during mirror observation." Further empirical research addressing both driver gaze and driver workload measures that investigate the influence of driving conditions, driving activities, and particular driving segments (e.g., merging into traffic and pulling into a bus stop) could provide valuable information for the designers of transit bus collision avoidance systems.

Tutorial 4: Integration of Collision Warnings

Introduction

The design guideline on page 2-6 of this document provides both a general introduction to the concept of warnings integration, as well as some general principles that can be used when considering how to integrate collision warnings. For the most part, the guideline seeks to identify broader issues and questions that designers should consider when integrating collision warnings from multiple collision avoidance devices.

A key objective of these guidelines for collision warning systems is to provide collision warning designers with sound human factors design principles that will aid the integration of warnings. Unfortunately, there is very little directly applicable data that can be used to develop specific, comprehensive guidance for the integration of collision warnings. This tutorial provides some additional discussion and perspective on this topic.

What is Warnings Integration?

A good starting point for providing a definition for “warnings integration” is to consider the larger requirement of *system integration.* System integration has been defined as “the successful putting together of the various components, assemblies, and subsystems of a system and having them work together to perform what the system was intended to do” (U.S. Air Force, 2003). This definition also helps to provide the larger context in which warnings integration should occur. That is, integration of collision warnings should take place within a broader effort to integrate the entire collision warning device. Depending on the overall purpose of the system, this might include physical integration of warning sensors, integration of components (e.g., cabling, communication buses, and vehicle data sensors), use of common processors for data fusion, integration of algorithms for determining the presence of threats and appropriate warning levels, and integration of DVI components such as displays and controls. In short, integration of collision warnings is a design activity that will occur at much broader level than just the DVI.

For our purposes, *warning integration* refers to the merging and organizing of individual collision warning components into a comprehensive, understandable, and interoperable system. This approach deliberately considers the driver of the collision warning-equipped vehicle as the focus and purpose of warnings integration. The goal of a warnings integration effort is to provide the driver with collision warnings that he/she can perceive, recognize, interpret, and—ultimately—respond to in a manner that improves driving performance and increases safety. The topic of “integration” is associated with a number of design issues, including:

- Management/prioritization of warnings in situations where multiple hazards are detected and the potential exists for multiple ICWs to be presented to the driver simultaneously (or near-simultaneously).[2]
- The implementation of distributed versus centralized visual displays.
- The implementation of distributed versus centralized system controls.

[2] In the remainder of this tutorial, we will use the term “simultaneous” to refer to hazards that are both truly simultaneous (occurring at exactly the same time), as well as for hazards that are “near-simultaneous.”

- The presentation of hazard-specific visual/auditory/haptic warnings versus master warnings.

As a practical matter, it would seem to be a rare event when a CWS device was required to manage more than one hazard/conflict simultaneously (i.e., occurring so close to one another—perhaps within 100 milliseconds—that the system would begin processing the second event before presenting a warning to the driver for the first event).

Key Integration Issues and Goals

The stages of warning comprehension and use are similar to those associated with in-vehicle icon comprehension suggested by Carney, Campbell, and Mitchell (1998) and Campbell, Carney, Richman, and Lee (2002). This issue is especially important for vehicles equipped with more than one collision warning device, considering the consequences of missed warnings or confused drivers. Within this framework, warning comprehension and use include:

Perception of the Warning
- Can the driver see/hear/feel the warning?
- If visual, can the warning be seen at various distances?
- If auditory, can the warning be heard when the driver's head is oriented in different directions?
- If tactile, can the warning be felt regardless of the driver's seating position and posture?
- Can the warning be perceived under various weather, roadway, and lighting conditions?
- If multiple warnings are presented simultaneously, are there any perceptual conflicts or masking of the warnings?

Recognition of the Warning
- Is the warning signal easily confused with other warnings or other in-vehicle messages?
- Does the driver recognize unique, identifying characteristics of the warning, such as the symbol(s) depicted in icons, specific characteristics (words, frequencies, repetition rates) of auditory warnings, and the placement and vibration patterns associated with haptic signals?
- If multiple warnings are presented simultaneously, will the driver still be able to identify/recognize individual warnings?

Interpretation of the Warning
- How well does the warning represent its intended message?
- Will drivers understand the warning when presented in the appropriate context?
- To what extent does the warning allow the driver to accurately assess the hazardous situation?
- Does correct interpretation of the warning's meaning require special knowledge particular to a culture, language, or driver age?
- If multiple warnings are presented simultaneously, will the driver confuse the meanings of individual warnings or misinterpret the combined set of warnings?

Response to the Warning

- o To what extent does the warning communicate the nature of the desired driver response?
- o Could the warning result in a “critical confusion” (i.e., a driver response that is the opposite of the intended response)?
- o If multiple warnings are presented simultaneously, will drivers be confused regarding the relative priorities of desired responses? Have these priorities been communicated to the driver?

In general, efforts to integrate collision warning systems should seek to avoid: overwhelming the driver (COMSIS, 1996), interfering with the driving task (Spelt, Tufano, & Knee, 1997), contributing to errors and annoyance (Lee & Kantowitz, 2005), as well as confusing or overloading the driver (Chiang, Brooks, & Llaneras, 2004).

The recent RDCW system FOT provides some information about operational aspects of system integration (LeBlanc et al., 2006). In particular, the RDCW system included separate LDW and CSW systems that contained some overlap in terms of warning presentation, with both using auditory displays for imminent warnings, haptic displays for cautionary warnings, and visual displays for both. Driver evaluations regarding the differentiability of the same-modality LDW and CSW displays suggest that there may be advantages to focusing on warning displays that are more different instead of just on optimal warning types that are more similar. In particular, the auditory warnings, which were the most different (abstract auditory tone versus descriptive speech message), were rated as easily distinguishable by most drivers. In contrast, there was less certainty about the distinguishability of the two haptic warnings, which differed in terms of their characteristics (e.g., location and temporal profile) but were essentially of the same type (i.e., seat vibrations). The visual displays were the most similar (differing only in terms of an arrow display element), and had the lowest distinguishability ratings, however, the secondary nature and reduced prominence of this display may also have contributed to this finding. These results are merely suggestive; however, they are consistent with the more general human factors principle that there are inherent limits to the number of different types of informational “codes” that drivers can quickly distinguish without having to take time or effort to decipher or figure them out.

This effort has implications for general display integration strategies. In particular, it may be advantageous to limit the number of warnings overall (e.g., use imminent warnings only), if this allows the use of warnings that are more easily differentiated from one another. Also, it may be advantageous to use more descriptive warnings (e.g., auditory icons or speech warnings instead of more effective abstract tones) if they provide a more intuitive coupling between each warning and its associated problem/response. Similarly, it may be worthwhile to use a few less optimal warnings (less optimal in an absolute sense) if they provide better differentiation from other warnings (e.g., one optimal auditory tone and a less optimal speech warning, instead of two optimal auditory tones that can be confused). At this point, apart from the suggestive results from the RDCW FOT, there is little research data specific to collision warning devices that provides guidance regarding which of these strategies is most effective and when it is most beneficial to use them.

Driving Scenarios that Highlight the Need for Warnings Integration

For the three collision warning devices that are the focus of these guidelines—forward collision, lane change/merge, and roadway departure—there are potentially up to seven unique driving scenarios that need to be addressed with respect to driver warnings:

1. Forward collision alone
2. Lane change/merge collision alone
3. Roadway departure alone
4. Forward collision + lane change/merge collision
5. Forward collision + roadway departure
6. Lane change/merge collision + roadway departure
7. Forward collision + lane change/merge collision + roadway departure

Guidelines for driver warnings associated with scenarios 1, 2, and 3 have been addressed in chapters 2 through 10 of these guidelines and scenario 7 is generally considered to reflect an extremely rare set of conditions and events. Najm (2006) has identified scenarios 4, 5, and 6 as being the key integrated test scenarios for collision warning devices providing forward collision, lane change/merge, and roadway departure warnings.

In an example of scenario 4 (forward collision + lane change/merge collision), the collision warning-equipped vehicle (or *host* vehicle) is in the left-hand lane of a four-lane divided highway, driving behind another vehicle (or *lead* vehicle), with a steady flow of fast-moving traffic in the right-hand lane. A hazardous situation emerges as the lead vehicle suddenly and rapidly decelerates, leading to a condition that could trigger the forward collision ICW. While hard braking might avoid or at least mitigate a collision with the lead vehicle, another option for the driver might be to change lanes. However, adjacent vehicles in the right-hand lane that are either next to the host vehicle or closing in from behind at a higher relative speed (if the host vehicle has begun decelerating) could also trigger a lane change warning.

In an example of scenario 5 (forward collision + roadway departure), the collision warning-equipped vehicle (or *host* vehicle) is in the right-hand lane of a four-lane divided highway, driving behind another vehicle (or *lead* vehicle), while entering a curve. A hazardous situation emerges as the lead vehicle suddenly and rapidly decelerates, leading to a condition that should trigger the forward collision ICW. Simultaneously, the curve-speed warning component of the roadway departure system detects that the host vehicle's speed is too fast for the curve.

In an example of scenario 6 (lane change/merge collision + roadway departure), the collision warning-equipped vehicle (or *host* vehicle) is in the left-hand lane of a four-lane divided highway, while another vehicle is driving in the right-hand lane, slightly ahead of the collision warning-equipped vehicle. The host vehicle drifts to the right, leading to a condition that could trigger both the lane drift component of a RDW system and an LCW. Note that this type of scenario may be less common, because recent implementation of RDW systems essentially provide most of the same warning functionality as LCW systems, which makes the latter system mostly redundant (LeBlanc et al., 2006).

Other scenarios requiring some level of warnings integration are possible, depending on the overall capabilities of an individual CWS. For example, consider a situation in which the driver in the right-hand lane of a four-lane divided highway receives an ICW from an FCW system, and—in response—begins to drive out of the lane onto the shoulder of the road. If the vehicle is also equipped with an RDW system, this could trigger an RDW, possibly confusing the driver and interfering with his/her response to the FCW. This is a somewhat unique situation in that it was the driver's response to an ICW that caused a situation triggering another warning, yet is it clearly a plausible one.

How should a collision warning device manage and prioritize warnings in these (and potentially other) situations involving multiple hazards and the possibility of presenting the driver with multiple warnings? Some options for addressing these situations, as well as some advantages and disadvantages associated with these options, are presented below.

Options for Integrating Collision Warnings

As noted earlier, there is very little directly applicable data that can be used to develop specific guidelines for the integration of collision warnings. Many data sources (e.g., Spelt et al., 1997) note the need for an integrated system to "manage and prioritize" in-vehicle information, but few describe how this might be implemented or how it might appear to a typical driver facing simultaneous hazards and their associated warnings. The general goals for warnings integration as well as the key integration scenarios outlined above, however, may allow us to begin developing a set of functional options for managing/prioritizing warnings when faced with situations involving multiple, simultaneous hazards. Thinking through these options, as well as their possible implications for driver perception and performance, might help to advance the development of integrated CWSs.

A first option would be to treat the multiple, simultaneous hazards independently. That is, to provide the driver with multiple warnings, each employing the same message timing, modality, and format characteristics as they would have in the case of a single hazard. Such an approach would generally allow the driver to determine the relative priority among multiple warnings and take the action(s) that he/she deemed appropriate. However, depending on the nature of the warnings (especially the modality), this approach might present simultaneous warnings that the driver may not be able to perceive (as in the case of distributed visual warnings) or understand (as in the case of simultaneous auditory warnings). Thus, in the case of scenario 4 above (forward collision + lane change/merge collision), there is a possibility that multiple auditory messages could be presented for ICWs, leading to auditory masking, incomprehensible messages, or driver confusion. Interference from warnings on driver responses is also a concern. In particular, a recent study conducted by Chiang et al. (2004) found that drivers changing lanes to avoid a conflict with a decelerating lead vehicle in response to a FCW were more likely to crash into a fast approaching side vehicle if they were presented with a subsequent LCW, than if no LCW was presented. The authors suggest that the presentation of the LCW may have overloaded drivers when their workload was already high.

A second option would be to prioritize the simultaneous hazards (using the ISO procedure described in Chapter 2) and to then adjust the timing of the warnings to reflect these priorities.

Thus, the higher priority warning could be presented first, followed by the second warning.[3] The goal would be to at least give the driver time to perceive and process the first warning before presenting the second warning. Although this option might avoid some of the perceptual conflicts associated with the first option, there is still a possibility of interference with the driver's response to the first warning (and confusing the driver or slowing the response) by presenting the second warning. There is also a possibility that the warning for the lower priority hazard may arrive too late for the driver to make an appropriate response, assuming that the driver is unaware of the hazard on his or her own.

A third option would be to shift the default presentation modality of the lower priority warning. For example, if the default presentation modality of both ICWs is auditory, the system could be configured to present the lower priority warning as either a visual or a haptic warning in order to reduce the possibility of perceptual conflicts and to increase the likelihood that both warnings will at least be perceived by the driver. This could still lead to confusion or response conflicts on the part of the driver. It might also inhibit the development of an accurate mental model of the system by the driver, since the modality used to present the second warning (in this case, the lower priority warning) changes depending on the number of hazards being addressed and the relative priority assigned to the hazards.

A fourth option would be to deliberately inhibit the presentation of a lower priority ICW, until the higher priority hazard no longer exists. This approach would certainly avoid: 1) perceptual conflicts, 2) masking of concurrent auditory messages, and 3) confusing the driver with the presentation of multiple messages. Of course, this may also mean that the warning for the lower priority hazard is not provided to the driver in time for the driver to perceive, process, and respond to the warning. This could lead to a collision if the driver does not perceive the lower priority hazard on his or her own or if the hazard situation is not otherwise resolved (e.g., through actions taken by other drivers).

Other options are possible, yet most are associated with the same or similar advantages and disadvantages as the four outlined above. For example, one could implement a combination of the second and third options and shift both the timing and the modality of the lower priority warning. Also, some have recommended that perhaps a master alerting signal—probably auditory, with localization cues to distinguish directionality—should be incorporated into multi-functional collision warning devices (see ISO, 2005). ISO suggests that a warning implemented as a speech signal (e.g., "Danger") may be the only signal that the driver has time to perceive and respond to. However, research conducted by Chiang et al. (2004) found that driver detection and identification of secondary warnings was lower with a master display, and that this type of display was less effective in prompting appropriate driver responses. More specifically, if a single master warning was used to indicate an FCW first followed by an LCW, drivers were 1) less likely to detect the second occurrence of the warning (indicating the lane change conflict) and 2) if they did detect it, drivers always interpreted it as a continuation of the first forward collision warning and not as a new lane change warning. Also, a master warning failed to prompt drivers to look at their mirrors during a lane change conflict, whereas a separate localized LCW was effective in prompting drivers to look at their mirrors 63 percent of the time. These

[3] The timing of the second warning, relative to the first warning, should reflect the guideline for warning timing presented in Chapter 2.

results suggest that careful consideration should be given to the effectiveness of a master-warning approach and perhaps further testing should be conducted, if this strategy is to be implemented in an integrated system.

Regardless of which strategy is implemented, one important design consideration should be to avoid warning solutions in which the presentation of a lower priority warning interferes with the driver's perception of, or necessary response to, a higher priority warning. For example, a front seat pan vibration used to warn the driver about excessive curve speed presented concurrently with, or just after, an imminent FCW could potentially disrupt the driver's hard braking response to the FCW. Similarly, if a driver's only safe response in a FCW situation is to steer onto the shoulder to avoid a hazard, then a steering wheel vibration or counterforce presented by an LDW system could potentially interfere with the driver's evasive steering actions.

Key Research Issues Associated with Warnings Integration

As seen in this discussion of warnings integration, there are—at present—perhaps more questions than answers surrounding this topic. Below, we identify (based on an analysis presented in Richard, Campbell, McCallum, & Brown, 2006) a number of research issues associated with DVI-related aspects of warnings integration.

- How should auditory warnings be used in multiple-warning situations? Should they be suppressed because dealing with simultaneous visual warnings already presents high demands for drivers, or should the auditory alert for the highest priority warning be presented?
- If multiple warnings are presented in close temporal proximity to one another, should rules for presentation modality be changed in order to avoid having two visual messages or two auditory messages presented at the same time? Should the higher priority visual warning be suppressed to avoid confusion with lower-priority visual-only warnings?
- What, if any, might be the role of **active vehicle control** under simultaneous hazard conditions? Is an automated system that makes vehicle control decisions and acts on them (e.g., automatic braking) an appropriate method to use for preventing or mitigating crashes? If CWS devices were to include such automated functions, what rules should be used to allocate functions between the system and the driver?
- What are the critical driver information processing capabilities, bottlenecks, and specific limitations in the context of having to respond to multiple simultaneous warnings? How does the presentation of multiple warnings affect drivers' ability to perceive/identify warnings, make decisions, and plan and execute necessary driving actions? What multiple-warning approaches are best suited to driver capabilities?
- How should controls for system on-off, sensitivity, and intensity be designed for systems with multiple capabilities? Should the system allow specific settings for each crash type (e.g., one for FCW, another for LCW, another for RDW), master settings, adaptive settings (the system makes these adjustments automatically), or none at all?

CHAPTER 12. EQUATIONS

Equation 1 (page 2-4)

When calculating priorities among CWS messages, for each message, calculate the priorities assigned by individual evaluators:

$p_{ij} = k_c c_{ij} + k_u u_{ij}$

where:

p_{ij} = the priority value for an individual message from an individual evaluator

c_{ij} , u_{ij} = individual scores for, respectively, criticality and urgency

k_c, k_u = individual weights for, respectively, criticality and urgency

For each message, calculate the average priority value across evaluators.

Equation 2 (page 4-10)

Defining symbol within an icon and visual angle calculations:

$$\text{Visual Angle} = \text{Arctan}\left(\frac{\text{Display Height}}{\text{Distance}}\right)$$

Equation 3 (pages 9-2 and 9-6)

For auditory displays:

Intensity = ambient noise level + 15 dBA

CHAPTER 13. ACKNOWLEDGEMENTS

Although four individuals are listed as the authors of this document, many more individuals have participated in the development of the *Human Factors Guidelines for Collision Avoidance Warning Systems*.

In particular, the authors would like to express their sincere thanks to Mike Perel, our NHTSA Contracting Officer's Technical Representative (COTR) on this project, as well as to Dr. Jim Foley and Eric Traube of Mitretek Systems for their help throughout this project. The direction, feedback, and advice provided by our NHTSA and Mitretek colleagues on this effort have been both timely and useful. We are also grateful to John Farbry of SAIC for his helpful comments on an earlier draft of this document.

We would also like to thank our administrative assistant at Battelle's Center for Human Performance and Safety, Ms. Diane Williams, for her patience and tireless efforts during the development of these guidelines.

We are also grateful for the assistance provided to us by a number of subject matter experts (SMEs) who volunteered their time and talents in order to make these guidelines more relevant and useful. Many of these individuals have been directly involved in the development and design of CWS devices for a number of years. They have provided the project team with an invaluable "end-user" perspective and have contributed to the effort by:

- Providing feedback about the desired content, format, and organization of the CWS guidelines;
- Suggesting source materials that should be used during guideline development;
- Providing review comments on draft materials developed by the Battelle team as part of the project;
- Providing information on recent advances in relevant CWS technology and product development; and
- Providing and commenting on ideas for high-priority, future research needs.

Overall, the guideline development team at Battelle has benefited enormously from the involvement of this group of SMEs in this project; we specifically wish to thank:

Klaus Bengler
BMW

Debby Bezzina
Visteon Corporation

Peter Burns
Transport Canada

John Hancock
Iteris

Steve Jahns
PACCAR Technical Center

Jim Keller
Honda R & D Americas, Inc.

Ray Kiefer
General Motors NAO Safety Center

John Kovacich
Eaton Corporation

Tom Mattox
Eaton Corporation

Michael Nowak
Eaton Corporation

Dean Pomerleau
AssistWare

Scott Pyles
Valeo Raytheon

James R. Sayer
UMTRI

Dan Selke
Mercedes-Benz, USA

Colleen Serafin
Visteon Corporation

John Shutko
Ford Motor Company

Tim Tiernan
Visteon Corporation

Louis Tijerina
Ford Motor Company

Hiroshi Tsuda
Nissan Technical Center North America

Alan Stevens
TRL

Margaret (Meg) Vais
Daimler Chrysler

Richard van der Horst
TNO

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APPENDIX A. SOURCES FOR SUMMARY OF CURRENT AND EMERGING CWS DEVICES

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January 2007

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