PRELIMINARY HUMAN FACTORS GUIDELINES FOR CRASH AVOIDANCE WARNING DEVICES

NHTSA Project No. DTNH22-91-C-07004

Prepared for

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

January 1996

COMSIS Corporation
8737 Colesville Road, Suite 1100
Silver Spring, MD 20910

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

Section | Page

TABLE OF CONTENTS (cont'd)

Section | Page

TABLE OF CONTENTS (cont'd)

Section | Page

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

TABLE OF CONTENTS (cont'd)

NOTICE

This document contains the preliminary guidelines for crash warning devices and the comments received during a formal review of the material by professionals in the field of Intelligent Transportation Systems (ITS). The original draft of these guidelines was circulated by NHTSA's Office of Crash Avoidance, to solicit feedback from the expert community. Comments were received through two primary means. First, copies of the draft were provided to interested parties, on condition that they provide comments back to NHTSA. Second, a formal workshop session on the guidelines was held as part of the 1994 IVHS America annual meeting. As a result of these efforts, the document received thorough review by a wide and diverse readership. Extensive comments were obtained on all sections of the document. The present update of the original report organizes and appends those comments, and cross-references them to the relevant sections of the guidelines.

The guidelines are considered preliminary as NHTSA is currently conducting an intense program of research in related areas which will contribute to the technical body of knowledge addressed by the guidelines in this document. In order for NHTSA and the industry to receive the full benefit of the review comments for further revisions of the guidelines, the comments included in Appendices A - C of this document are presented in an unedited format. The individual guidelines refer the reader to a related appendix section to obtain additional information. Additionally, a list of acronyms and a glossary have been added to the original document and are contained in Appendices D and E.

Appendix A is organized by guideline section. If a section is not represented in this appendix, no comment was received.

Appendix B contains responses to 25 questions put forward to a working group session on the preliminary guidelines, held by the IVHS America Safety and Human Factors Committee at the annual meeting of IVHS America held April, 1994.

Appendix C contains general comments that do not fit into either of the above categories.

Appendix D: List of acronyms

Appendix E: Glossary of terms

PREFACE

The document that follows presents a set of preliminary guidelines for the human factors aspects of in-vehicle crash avoidance warnings. These Guidelines contain a section on generic, or system, requirements that are intended to be applicable to all crash avoidance warning devices. There are also sections addressing four specific types of crash avoidance warning devices: blind spot warning devices, backup warning devices, driver alertness monitoring devices, and headway warning devices. These four classes of devices were selected as prototype examples for the development of human factors functional specifications. Various other types of crash avoidance warnings may be used in vehicles as well, but these are not specifically treated here, except by those recommendations presented as generic or system requirements. The Guidelines deal specifically with the design of the interface with the driver, that is, how information is displayed and how the device is operated. These human factors guidelines are intended to be independent of the sensor technologies employed by any particular device, and begin with the assumption that the sensing technology is acceptably accurate and reliable. It is not the intent of this effort to design a particular warning device or system of devices. Rather, the Guidelines concern the features and functional requirements that any device, or collection of devices, should meet in order to perform adequately.

One purpose of developing these Guidelines was to uncover those areas in which additional research is required in order to define optimal criteria. In many cases, where the empirical basis on which the Guidelines should be based is not adequate, "best judgment" recommendations were made. Within this document, issues are defined explicitly so that they can be reviewed and debated by specialists within the human factors and IVHS communities.

Various types of in-vehicle crash avoidance warning devices may be present in unpredictable combinations in future vehicles, and will need to operate effectively in a driving environment that will include many possible combinations of other vehicle displays, controls, and information systems. Warning devices that are not designed with consideration of the other features that may be functioning simultaneously in vehicles may not perform optimally, and might even generate safety problems of their own. One purpose of these Guidelines is therefore to propose recommendations that will anticipate and avoid many of the problems that can come about if warning products are designed in a piecemeal fashion. The Guidelines are intended to be applicable to crash avoidance warning devices that may be designed into the original vehicle, or added on later as separate products. It is possible, however, that as these devices become more widely used and as these Guidelines more widely debated, safety standards will emerge which specify the combinations of devices that are required and/or permitted within the vehicle. The Guidelines are intended to be general enough to permit the use of various display technologies, from traditional automotive displays to head up displays, CRTs, synthetic speech, or other formats, as long as functional requirements are met. Ultimately, whatever the combination of warning types and display technologies, the warning system must insure the rapid and accurate perception of hazards, quick and appropriate responding, minimal distraction from other aspects of the driving task, and acceptability to the full user population. To accomplish this, the number and complexity of individual warnings and other information displays must be constrained, and potential information conflicts must be handled.

There is a potential for a great number of distinct warning situations as more "smart" technologies find their way to the highway vehicle application. These Guidelines directly address only the category of "in-vehicle crash avoidance warnings," as these are defined in the Guidelines; and within this category, only four specific example types of in-vehicle crash avoidance warning devices are explicitly considered (headway warning devices, blind spot warning devices, backup warning devices, and driver alertness monitors). Numerous others are being developed or considered, such as lane deviation or run-off-road warnings, intersection-related crash avoidance warnings, impending rollover warnings, low road friction warnings, and speed-related warnings. However, in addition to these in-vehicle crash avoidance warnings, there are various other categories of warnings that may be presented to the driver. For example, there may be vehicle status warnings, which alert the driver to such conditions as low tire pressure, malfunctioning vehicle systems, unlatched doors, and so forth. There may be advance warning signals transmitted to the driver from more remote roadway sites or from other vehicles. These warnings could alert the driver to such conditions as approaching emergency vehicles, police activity, lane closures, icy spots, fog, rail-highway grade crossings with approaching trains, and a variety of other situations. There may also be "warnings" that are not directly safety related, but alert the driver to other sorts of driving errors or problems. For example, an in-vehicle navigation system may warn the driver of an impending turn, alert the driver to navigational errors, or warn of roadway congestion ahead. All of these categories of warnings, and the many distinct specific hazards within them, have some necessity of claiming the driver's attention. Since many developing warning products have been considered in an isolated fashion, the means for interfacing with the driver has seldom been considered in the full context of driver warning situations. Essentially any one product is designed to be effective as though it were the only warning device that might be present. The Guidelines presented here have attempted to take into account the potential for there to be various categories of warning types, and numerous specific hazards to be warned about within any one of them. Failing to deal with the likely proliferation of warnings, in addition to many other types of in-vehicle information, raises the potential for driver confusion, overly complex displays, conflicting messages and priorities, and slow or inaccurate driver reactions.

In developing these Guidelines, the standards and recommendations from many other warning systems applications were reviewed and evaluated. These included such applications as aviation (e.g., cockpit and air traffic control), process control (e.g., nuclear power plant control rooms), medical devices, military equipment, and highway systems. Although useful recommendations and findings were uncovered from many of these domains, one of the striking findings was the uniqueness of the vehicle crash avoidance warning situation. Warning practices from other areas were often inappropriate because of some important differences from the present application. Briefly, these included the following:

a. Temporal Demands. The temporal demands for in-vehicle warning practices are typically much more time-critical than for other applications. For a potential crash situation, there may be only a second or two between the recognition of conflict and the moment of the impact. In contrast, emergency situations in other contexts may be measured in tens of seconds, or even minutes. In other applications, direct view of the external context may also be less informative, and the needs for complex problem solving may be greater. These differences may have very important implications for the type or level of information provided, the mode of presentation, and so forth.

b. Situational Concerns. For most other applications, the standards or recommendations apply to a workplace environment; this is not the case for many vehicle applications, particularly automobiles. This difference has many implications in terms of control of the environment, the acceptability of constraints and practices, assumptions about the user, etc. As a consumer product, the automobile application also may have different trade-offs between rigid standardization of displays versus the flexibility to make products unique, or targeted to different market segments, or integrated with different layouts and features. The acceptable level of intrusiveness or annoyance, and tolerance for false alarms, may be quite different. Also, there is often a social context to driving. The presence of other passengers in the vehicle means that various driver warnings may be public. Consumer acceptance of an in-vehicle warning device, or behavioral reactions to the warning, can be influenced in various ways by the social context (e.g., embarrassment, feelings of competence, need to appear daring or competent to peers).

c. System Integration. In other applications, the workplace is designed as an integrated system, or at least as major subsystems, and the system requirements can be well defined. For vehicle applications, many potential warning devices may be aftermarket add-ons, or options, not integrated into the original design of the vehicle. The nature of the vehicle environment itself, with regard to information systems, displays, and controls, is evolving and not fully predictable, nor is it likely to be consistent from vehicle to vehicle. The driver's "task" can vary considerably as a function of other in-vehicle systems (e.g., cellular phones, route guidance displays, head up display formats), so that the optimal means for integrating crash avoidance warning devices, in a system context, is problematical.

d. User Population. In other applications, the population of users is much less variable. Nearly anyone from teenagers to the very old can obtain and use a drivers license, including those with physical, sensory, or cognitive deficits. Drivers receive minimal initial training, often little or no refresher training, and no training with specific new vehicles or devices. In contrast the users of warning systems in other applications (e.g., pilots, air traffic controllers, control room operators, medical technicians, and so forth) may be highly selected, relatively homogeneous, well trained, and supervised or monitored.

For these reasons, as well as application-specific considerations, the practices established for other applications are often not reasonable for the in-vehicle environment.

Although the Guidelines address many details of implementation, some of the major features of these recommendations are highlighted here to provide some overview of what an in-vehicle crash avoidance warning system would look like:

a. Multiple Levels of Warning. The most effective signals for alerting a driver are characterized by their intrusiveness and sense of urgency. However, these same features make them particularly annoying when the warning is unwarranted (i.e., nuisance or false alarms). More conservative assumptions about driver reactions and responses will lead to a greater level of overall protection, but will also result in more undesirable alarms and poorer user acceptance (i.e., annoyance, degraded perception of warning validity), and this problem will be compounded when multiple warning devices are present in the vehicle. As a general approach to minimizing the conflict between broader protection and greater annoyance/degradation, these Guidelines recommend multiple levels of warning for any particular warning device. The highest level of warning, termed an "imminent crash avoidance warning," uses a more urgent and intrusive signal. Cautionary warnings provide the driver with greater advanced warning, in a less disturbing form.

b. Unique Imminent Crash Warning Signals. For each potential signal modality (e.g., visual, acoustic, voice, tactile), there are features that are uniquely reserved for only imminent crash avoidance warnings. These features are selected to insure a conspicuous and urgent warning message, and to guarantee that such warnings are immediately distinguishable from any other sort of message that may be presented in the vehicle.

c. Dual Modality for Imminent Crash Warnings. No warning modality will be uniformly effective across the broad range of vehicle users and internal and external driving environments. Therefore, imminent crash avoidance warnings are normally presented in two modes (e.g., visual and acoustic). A visual display is used as the redundant mode because it has advantages for dealing with simultaneous hazards.

d. Non-Specificity to Sensor or Display Technology. These Guidelines discuss the features of warning displays, but they intentionally do not recommend specific types of sensors or displays. Any sensor or display may be used, as long as it meets the criteria described. This permits flexibility in design and system integration, and an ability to respond to new technologies or changes in cost or availability.

e. Warning Prioritization. More than one warning event might occur at a given time, and the warning system requires rules for handling these events in a way that facilitates optimal driver behavior. Various schemes for prioritization can be developed depending on the parameters a sensing system can measure (e.g., time-to-collision), the combination of sensors available, and the degree of existing system integration and intelligence. These Guidelines provide a basic prioritization scheme that can underlie systems with varying degrees of capabilities.

f. Compatibility with Driver Behaviors. Characteristics of the warnings must be compatible with driver behavior. This includes both normal driver actions that are related to the maneuvers being monitored (e.g., changing lanes, backing up), and also to the emergency vehicle control responses that are desired in reaction to the warning. Many of the specific examples of this general rule may be found in the Guidelines sections addressing specific devices.

g. Warning Message Content. There has been debate over the "best" type of information to provide the driver: a general warning signal, an indication of the type of hazard, an indication of the location of the threat, and/or the specification of a particular driver action. The position here is that the answer to this question is probably device-specific. However, data are lacking for this important issue, so that in many cases the Guidelines remain broadly permissive.

h. Device Status and Controls. The Guidelines contain provisions to assure that the driver is aware of the operational status of the warning device and will not be reliant on a device that is not functioning. There are also provisions to guarantee that a driver's expectancies regarding the setting of controllable features (e.g., sensor sensitivity, warning intensity) will be met.

i. Minimization of Nuisance Warnings. The criteria for triggering a warning will always represent some trade-off between broader protection and the frequency of undesired warnings. To whatever extent data permit, these criteria need to be based on available information about crash scenarios and driver capabilities. However, these Guidelines also attempt to minimize nuisance alarms by carefully defining the conditions of application, anticipating likely nuisance alarm scenarios, and providing for user sensitivity control or override where appropriate.

PRELIMINARY HUMAN FACTORS GUIDELINES
FOR CRASH AVOIDANCE WARNING DEVICES

1.0 INTRODUCTION.

Technological advances are making it possible to design new devices that can assist the driving public in achieving safer and more efficient travel on our highways. One such category of devices is crash avoidance warning devices, which currently exist in various stages of development. It is important that such devices be designed from a driver-centered perspective if drivers are to obtain maximum performance and safety benefits. This document contains human factors guidelines to facilitate driver-centered design of crash avoidance warning devices and systems.

1.1 PURPOSE.

The purpose of this document is to set forth preliminary human factors guidelines for the design of in-vehicle crash avoidance warning devices and systems.

1.2 OBJECTIVE.

This document has two objectives:

a. To provide human factors design guidance to developers of in-vehicle crash avoidance warning devices and systems and to other individuals and organizations involved in the integration of such devices within vehicles; and

b. To illuminate the state of human factors knowledge with respect to in-vehicle crash avoidance warning devices and, thereby, the existing gaps in the knowledge base.

[*See specific 1.2 comments in Appendix A*]

1.3 DEFINITION AND FUNCTIONS OF CRASH AVOIDANCE WARNINGS.

A **crash avoidance warning** is defined as an in-vehicle presentation of information alerting the driver to a probable collision situation requiring immediate attention. A crash avoidance warning is **not** intended to continuously present status information requiring monitoring by the driver, but to capture the driver's attention in a hazard situation.

Crash avoidance warnings may serve several functions. The main purpose of the warning is to **alert** the driver to a hazardous situation requiring some action to avoid a collision. Ideally, warnings should also **quicken or refine** driver response to a hazard by providing information that allows the driver to rapidly determine an appropriate response. In addition, the warning may serve to **educate** the driver by providing feedback concerning desirable practices or unsafe acts.

A **crash avoidance warning device** is a unit designed to perform a single crash avoidance warning function (e.g., headway detection, blind spot monitoring).

A **crash avoidance warning system** is a unit designed to integrate the functionality which would normally exist in more than one warning device.

1.4 SCOPE OF THIS DOCUMENT.

This document provides general human factors design guidelines applicable to all in-vehicle crash avoidance warning devices and systems. It also provides specific human factors guidelines for the design of four types of crash avoidance warning devices:

a. Blind spot warning device;
b. Backup warning device;
c. Driver alertness monitoring device; and
d. Headway warning device.

The decision to develop guidelines for these particular types of crash avoidance warning devices was based on an analysis of existing crash avoidance technologies and concepts (COMSIS Corporation and Castle Rock Consultants, 1992). Each was evaluated in terms of several factors, including its current status/availability, the potential safety benefits of the technology, and the projected cost of implementation. The four device types chosen represent a set of promising applications based on these criteria, and also provide a diversity of human factors issues for consideration.

The human factors design guidelines provided in this document were derived from an assessment of the performance capabilities and limitations of vehicle operators, and the functionality necessary for effective, efficient, and safe use of crash avoidance warning devices by those operators. Information sources for this assessment included:

a. Current crash avoidance warning devices and prototypes;

b. Warning practices in other advanced technology applications;

c. Theoretical and empirical research concerning vehicle warnings and driver behavior; and

d. Analyses of crash characteristics.

Finally, a constant consideration during the development of these Guidelines was the fact that a crash avoidance warning device does not exist in isolation within a vehicle. There may be more than one crash avoidance device and there are other systems, including information systems (e.g., for navigation), status systems (e.g., low fuel; unlatched door), communication systems, other types of advance warning systems (e.g., beacon indicating a lane closure situation ahead), and entertainment systems, which must co-exist with crash avoidance warning devices and systems. Thus, these Guidelines have been written giving explicit attention to system integration issues in the hope of avoiding the problems that typically arise when devices are designed in a piecemeal fashion.

[*See specific 1.4 comments in Appendix A*]

1.5 APPLICATION OF THE GUIDELINES.

The Guidelines presented in this document are applicable to the design of all in-vehicle crash avoidance warning devices, whether integrated within the vehicle at the time of manufacture or added to an existing vehicle as separate, stand-alone devices. This document does not limit the selection of device architectures or sensor, display, and control technologies for crash avoidance systems.

It is important that the Guidelines not be applied blindly, especially in light of the limited empirical support available in some cases (see Section 1.6). A thorough understanding of design criteria and overall design objectives is necessary to apply these Guidelines appropriately. In practice, trade-offs that occur during the design process may require certain Guidelines to be modified or replaced.

1.6 LIMITATIONS OF THE GUIDELINES.

To the extent possible, the Guidelines in this document are based on empirical research data and generally accepted human factors practice. Because of the uniqueness of the crash avoidance warning situation and the relative recency of research developments in this area, many of the Guidelines are based on limited empirical data. Each recommendation is followed by supporting rationale which discusses the extent to which a given guideline is supported by research data or extensive practical application.

2.0 GENERAL GUIDELINES.

This section contains general human factors guidelines for the design of crash avoidance warning devices and systems which employ multiple warning devices.

The recommendations presented in the General Guidelines section are based on the assumption that there will be multiple types of warning devices in vehicles, as well as other types of displays that will compete for driver attention. Although many of these warning devices are being developed piecemeal, it would be optimal to integrate all warnings, or more broadly all information, into a fully integrated system, designed from the beginning to work as a system. However, the Guidelines are not based on the assumption of full integration of logic, on any specific array of devices, or on any assumed level of system intelligence. These are general guidelines intended to cover all appropriate implementations of crash avoidance warning devices. Specific guidelines are provided for four specific warning devices, as exemplars. However, Section 2.0 concerns those generic characteristics, common to all warning devices and combinations of warning applications that can be stated without regard to the specific components of the device or system.

2.1 DEVICE OPERATION.

2.1.1 DEVICE ACTIVATION/DEACTIVATION.

2.1.1.1 Application of Power.

Power should be applied to the warning device when the vehicle ignition switch is turned on even if the device is capable of being turned off manually during vehicle operation. This application of power should place the device into the standby mode of operation (e.g., device is receiving power, but sensors and warning interface are not activated). Any device which must be physically attached to or worn by the driver (e.g., driver alertness monitoring devices) is excepted. Such devices should be manually turned on by the driver, and should not be automatically turned on with the vehicle ignition switch.

Drivers cannot be relied on to turn on their crash avoidance warning devices each time they turn on the vehicle ignition. Therefore, warning devices should turn on automatically each time the vehicle is started. One exception to this recommendation concerns devices which must be attached to or worn by the driver, such as driver alertness monitoring devices. Such devices should not be turned on automatically with the vehicle ignition switch, but should require the driver to manually activate the device, or otherwise have power applied only when the device is being used. Automatically applying power to devices which must be attached to or worn by the driver will likely lead to a proliferation of nuisance alarms when the device is not being used.

[*See specific 2.1.1.1 comments in Appendix A*]

2.1.1.2 Activation for Use.
Crash avoidance warning devices should be automatically placed from the standby mode into an active mode for hazard detection only during applicable driving situations. Specific conditions for activating each device are defined in Sections 3 through 6 of these Guidelines.

Maintaining all warning devices/functions in an active mode regardless of their need may increase the number of false warnings and significantly reduce the driver's confidence in the system. For example, keeping a backup warning device activated while moving forward serves no useful purpose and may produce false warnings that may confuse or annoy the driver.

[*See specific 2.1.1.2 comments in Appendix A*]

2.1.1.3 Termination of Power.
Electrical power supply to crash avoidance warning systems should be automatically terminated when the vehicle's ignition switch is turned to the OFF position. The driver should also be permitted to manually terminate electrical power to the device at any time during vehicle operation by means of an ON/OFF switch.

Since drivers cannot be relied on to turn off all equipment when leaving the vehicle, power to warning systems should be automatically terminated when the vehicle's ignition switch is turned off. However, because it may not be possible to predict, or design for, all potential driving conditions under which the warning device does not perform appropriately, the driver may be allowed to turn a warning system off to reduce or eliminate false or nuisance warnings generated by the system.

[*See specific 2.1.1.3 comments in Appendix A*]

2.1.2 DEVICE TESTING.
All warning devices should incorporate capabilities for built-in diagnostic testing, failure indication, and manual testing of warning displays.

2.1.2.1 Built-In Diagnostic Testing.
All warning devices should include built-in diagnostic testing to verify that the device is capable of operating within specified performance limits. Diagnostic testing should be performed automatically each time the ignition switch is turned on. All devices that pass diagnostic testing should be automatically placed into a standby mode. All devices that fail should be automatically placed into a failure mode (see Section 2.5.4).

Drivers must be assured that the warning devices, including the means used to display warnings, are functioning properly. It cannot be assumed that drivers will manually test all devices before driving. Since the driver will rely on the warning devices, confirmation of proper functioning is required. Testing, therefore, should be performed automatically to assure the driver that the devices are functioning within specified performance limits.

[*See specific 2.1.2.1 comments in Appendix A*]

2.1.2.2 Failure of Multi-Sensor Devices.
For warning device displays that are capable of being activated by more than one sensor, the failure of any one of the sensors should be treated as a failure of the full device, and so indicated by the device's status indicator(s).

Some warning devices may detect targets or other critical situations (e.g., dangerous closing rate, serious impairment of alertness) using several sensors working in conjunction with one another to activate a single warning display. If one of these sensors is not operational, performance of the device will be degraded due to resulting "holes" in the detector field or inadequate detection of other situational parameters, and the driver may place unwarranted reliance on the device. Therefore, failure of any one sensor component should trigger an indication of warning device failure, even if the remaining sensors continue to operate properly.

[*See specific 2.1.2.2 comments in Appendix A*]

2.1.2.3 Warning Display Testing.
The driver should be provided with the capability to test each warning display manually at any time during vehicle operation. The display should be activated for a sufficient time period (approximately 5 seconds) to permit manual adjustment of display intensity (e.g., volume, brightness).

The driver must be confident that each warning display is not only functioning properly but that it is also capable of being perceived under the anticipated environmental conditions. Manual adjustment of warning intensity or volume will take up to 5 seconds to accomplish under most circumstances. Provision for manual control of warning volume or intensity is stated as a requirement in most human factors standards and guidelines (NUREG 0700; DOE-STD-HFAC; MIL-STD-1472D).

[*See specific 2.1.2.3 comments in Appendix A*]

2.1.2.4 Fail Safe Design.

Crash avoidance warning devices should be designed to fail in a safe manner. Failure should not cause critical functions (e.g., automatic prioritization of detected hazards) to produce false warnings. Malfunctioning systems should be automatically placed in a failure mode. The failed condition should be displayed to the driver by means of a status indicator (see Section 2.5.4).

The primary purpose of crash avoidance warning systems is to bring the driver's attention to hazards that may result in a collision. Prioritization of hazards should be accomplished to identify critical hazards requiring immediate attention and a quick response from the driver. Failure of a warning system, therefore, should not result in false warnings being presented to the driver, especially imminent crash avoidance warnings which require an immediate control response.

[*See specific 2.1.2.4 comments in Appendix A*]

2.1.3 PARAMETER INITIALIZATION.

Operational parameters (e.g., detector sensitivity, display intensity) for warning devices should provide some positive indication or signal to the driver if non-default, user-selected settings are in effect when the vehicle's ignition switch is turned on, or the operational parameter should be automatically reset to pre-established default levels.

Since there may be multiple users of the vehicle, operational parameters should either clearly present user-selected settings to the driver, or reset to default levels each time the ignition switch is turned on. Values may have been previously set to accommodate a particular driving situation (e.g., noisy environment, night driving) or a particular driver. Therefore, such requirements will ensure that the current driver is either initially informed of non-default settings or is provided with adequate default settings (i.e., users should expect default settings unless told otherwise).

[*See specific 2.1.3 comments in Appendix A*]

2.2 LEVELS OF WARNING.

All warning devices should be capable of generating at least two levels of warning - imminent crash avoidance warnings and cautionary crash avoidance warnings. Devices which provide continuous analog-type warnings (e.g., graded warnings) should provide an obvious change in the warning display when the level of warning changes from a cautionary to an imminent crash avoidance warning.

Research supports a multiple level priority system for alerting situations (Veitengruber, Boucek, and Smith, 1977; Berson *et al.*, 1981). The highest level of warning, termed an "imminent crash avoidance warning" in the Guidelines, alerts the operator to a situation which requires an immediate corrective action.

The next highest priority level, a "cautionary crash avoidance warning", alerts the operator to a situation which requires immediate attention and may require a corrective action.

The most effective signals for alerting a driver are characterized by their intrusiveness and sense of urgency. However, these same features make them particularly annoying when the warning is unwarranted (e.g., nuisance or false alarms). More conservative assumptions about driver reactions and responses will lead to a greater level of overall protection, but will also result in more undesirable alarms and poorer user acceptance (annoyance, degraded perception of warning validity). This problem will be compounded when multiple warning devices are present in the vehicle. As a general approach to minimizing the conflict between broader protection and greater annoyance/degradation, multiple levels of warnings are recommended for warning devices. Imminent crash avoidance warnings use a more urgent and intrusive signal, while cautionary warnings provide the driver with greater advanced warning in a less disturbing form.

[*See specific 2.2 comments in Appendix A*]
[*See Review and Discussion Issue #12, in Appendix B*]
[*See Review and Discussion Issue #17 in Appendix B*]
[*See Review and Discussion Issue #23 in Appendix B*]

2.2.1 IMMINENT CRASH AVOIDANCE WARNINGS.

Imminent crash avoidance warnings are to be used only where criteria for imminent crash avoidance situations are met. Features reserved for this category of warning should not be used for other situations.

DEFINITION OF IMMINENT CRASH AVOIDANCE SITUATION: An imminent crash avoidance situation is one in which the potential for a collision is such that it requires an immediate vehicle control response or modification of a planned response in order to avoid a collision.

This definition is intended to insure a situation in which there is an unambiguous need for immediate action. This will help protect the perceived validity of imminent crash avoidance alarms, promote immediate responding, and limit problems of annoyance due to unnecessary, highly intrusive alarms.

FEATURES: Imminent crash avoidance warnings must be presented in at least two modes. One mode must be visual, and one must be auditory or tactile. For each mode, the warning should incorporate those features uniquely reserved for imminent crash avoidance situations (see Sections 2.4.1, 2.5.2).

There are several reasons for the requirement for multiple modes of warning. First, no single mode will be effective for all potential users under all anticipated operational conditions. Because imminent crash avoidance warnings are of the highest priority, redundancy is critical. Second, warnings that do not require any specific physical orientation of the sensory receptors are essential to insure immediate perception. Vision does not meet this criterion (i.e., the driver might not be looking in the direction of the display), unless there is an obvious change in ambient illumination within the vehicle, which is an unlikely design feature. Acoustic signals or speech messages, however, do not require any particular orientation of the body for recognition. These signals are also generally more intrusive than visual displays and are generally recommended in human factors guidelines for the most serious warnings (MIL-STD-1472D; Van Cott and Kinkade, 1972; Salvendy, 1982). Tactile warnings are not well understood, and should be used cautiously pending further research, but they do have the potential for warning without regard to driver position.

Even though an acoustic or speech (or perhaps tactile) cue is required by the urgency of the imminent crash avoidance situation, there is also a necessity for a visual display. This is required to handle potential crash situations in which there is more than one hazard and where multiple warning devices are present (e.g., headway warning and blind spot warning). Acoustic and/or speech signals alone will be mutually interfering, and information about the location and/or nature of each hazard may be lost. The additional visual display will provide distinct cues for each hazard without obscuring one another. Thus, the acoustic or speech (or tactile) aspect of the imminent crash avoidance warning is superior for conveying an urgent warning quickly and reliably, while the visual aspect provides redundancy for difficult perceptual conditions, immediate unambiguous information about the location or nature of the hazard, and an ability to present multiple types of warnings without mutual interference.

The requirement that there be features exclusively reserved for imminent crash avoidance warnings is a key provision. The number and mix of crash avoidance warning devices, as well as other types of warnings and messages potentially in the vehicle, is not predictable (see Section 1.4). Guidelines for human factors design generally caution about the difficulties the human operator has when there are a substantial number of different auditory signals. For example, Sorkin (1987) cites studies that suggest a maximum of four to six distinct signals. Where absolute discrimination is required, MIL-STD-1472D specifies a maximum of four signals. Most of these recommendations are based on military or aviation applications, where the operators may be highly trained. Thus, for the ordinary driving situation, with a broad population of minimally-trained users, the problems of multiple warning codes will be even more acute. Having separate codes for all potential warnings may result in confusion and delayed responding. Voice messages may be more capable of distinguishing among different events, but there is a time requirement for speaking the full message. Unique voice characteristics would convey the "imminent crash" aspect of the message more immediately. For this reason, it is recommended that for every warning modality used, there are unique signal aspects that reliably indicate that this is a high-priority warning that requires immediate action. Specific elements of the message itself, (e.g., hazard location, type of hazard) may be included in the warning display, but the general message of an imminent crash situation should be unambiguous even to an untrained, unfamiliar, and inattentive driver. Those aspects of a display that should be unique to imminent crash avoidance warnings are discussed in the appropriate subsection for each mode of presentation (see Sections 2.4.1, 2.5.2).

[*See specific 2.2.1 comments in Appendix A*]
[*See Review and Discussion Issue #13 in Appendix B*]
[*See Review and Discussion Issue #24 in Appendix B*]

2.2.2 CAUTIONARY CRASH AVOIDANCE WARNINGS.

Cautionary crash avoidance warnings are to be used where criteria for the cautionary crash avoidance situation are met. These warnings are lower in urgency than imminent crash avoidance warnings, but are still intended to address time-critical situations. Cautionary warnings are intended to capture the attention of the unaware driver, rather than require deliberate monitoring by the driver.

DEFINITION OF CAUTIONARY CRASH AVOIDANCE SITUATION: A cautionary crash avoidance situation is one in which the potential for a collision requires immediate attention from the driver, and which may require a vehicle maneuver, but which does not meet the definition of an imminent crash avoidance situation.

Cautionary crash avoidance warnings are lower in urgency than imminent crash avoidance warnings, but still deal with potential crash events that require the driver to be aware of the hazardous situation and bring it under control. These warnings are distinct from, and more urgent than those that are not time critical (e.g., advance warning of a lane closure ahead) and those that are not collision-related (e.g., engine status, navigational information).

FEATURES: Cautionary crash avoidance warnings should be presented visually or by means of auditory or tactile signals that are less intrusive and annoying than imminent crash avoidance warnings. Cautionary crash avoidance warnings must meet the warning requirements of these Guidelines and may not incorporate the features reserved for imminent crash avoidance warnings (see Sections 2.4.2, 2.5.3).

Because they employ less stringent criteria, cautionary crash avoidance warnings will normally provide an earlier warning than imminent crash avoidance warnings, but this will result in many more false or nuisance warnings. In order to provide better user acceptance for the warning system, and to protect the special status and perceived validity of the most critical warnings, cautionary warnings must be less intrusive and annoying. This is consistent with general human factors practice (MIL-STD-1472D; Van Cott and Kinkade, 1972; Salvendy 1982), which recommends that acoustic and voice displays be used primarily for critical situations, those situations requiring a rapid response, or where environmental or task conditions make visual perception difficult. Visual displays are generally less annoying than acoustic or voice messages, and are less susceptible to masking from other in-vehicle messages. For this reason they are generally preferred for cautionary warnings. However, where the application makes visual warnings ineffective, acoustic cautionary signals may be required. In these cases, intrusiveness should be limited. Auditory and visual display guidelines, Sections 2.4 and 2.5, respectively, provide guidance for making these warnings acceptably conspicuous, with some limitation on the potential for poor user acceptance.

[*See specific 2.2.2 comments in Appendix A*]
[*See General Comments in Appendix C*]

2.3 WARNING PRESENTATION.

[*See Review and Discussion Issue #6, Comment 5 in Appendix B*]
[*See Review and Discussion Issue #7, Comment 1 in Appendix B*]

2.3.1 SYSTEM QUERY.

Information should be provided to the driver whenever a warning situation occurs. The driver should not have to directly request information from the system (i.e., query the system).

Although nuisance warnings could be reduced if a signal is provided only when the driver requests information (i.e., queries the system), the use of a "query" mode of operation is not recommended. Such a design requires an active response from the driver and serves more as a decision aid than an alert. Much less effort is required to simply glance at a visual display. Furthermore, the response requirement adds time to the perception-reaction time process. It is also likely that hazardous situations may arise as a result of some impulsive driver action or from inattention, neither of which would be consistent with querying the device. Therefore, it is preferred that a signal be presented whenever the system is activated and a hazardous situation exists, rather than having a system that only informs the driver when queried.

[*Specific 2.3.1 comments in Appendix A*]

2.3.2 PRIORITIZATION OF MULTIPLE WARNINGS.

Multiple imminent crash avoidance warnings occurring simultaneously should be automatically prioritized in terms of their severity and urgency. Only the highest priority crash warning should be presented in the auditory or tactile modality. All crash avoidance warnings should be presented simultaneously in the visual modality. Crash avoidance warnings should take precedence over all other in-vehicle warnings. Systems with simple algorithms should employ the following prioritization scheme for presenting multiple simultaneous crash avoidance warnings (1 = highest priority, 4 = lowest priority):

- **1: Target-specific imminent crash avoidance situation**
- **2: Non-target-specific imminent crash avoidance situation**
- **3: Target-specific cautionary crash avoidance situation**
- **4: Non-target-specific cautionary crash avoidance situation**

Target-specific warnings are those which have an identifiable collision source (e.g., car or obstacle in the roadway ahead, vehicle in the blind spot). Non-target-specific warnings indicate non-directional hazardous situations where physical collision sources are not sensed (e.g., impaired driver alertness, low road friction).

Systems which have the capability to perform sophisticated time-to-collision analysis or more intelligent analyses of the driving situation may use higher-level prioritization algorithms.

Crash avoidance warnings are only one type of information source that will be available to the driver in future vehicles. The driving environment may include navigation systems, route guidance systems, traffic information systems, communication systems, and an array of entertainment systems. In addition, there may be conversation within the vehicle itself. All of these sources of information presented to the driver will increase the cognitive workload on the driver. Therefore, prioritization rules should ensure that the driver's attention is directed at the most serious hazard first (MIL-STD-1472D, DOE-STD-HFAC, NUREG 0700). It is important that crash avoidance warnings are presented in a manner which will immediately capture the driver's attention and allow the driver to focus on the crash avoidance task. Given the time criticality of crash avoidance warnings these must take precedence over all other messages.

The need for prioritization is also important within the category of crash avoidance warnings. Because of the time critical nature of such warnings, the driver must be able to determine the hazard and the appropriate response quickly. The display of multiple warnings, with no indication of source of the warning, will create confusion, indecision, and inappropriate responses on the part of the driver. Therefore, the crash avoidance system must provide the driver with an immediate indication as to the nature of the hazard. Imminent crash avoidance warnings also must, by definition, represent the highest order warning, since they require immediate action on the part of the driver. The distinction between target-specific and non-target-specific warnings follows from the idea that once a target has been recognized, immediate collision probability has become much greater and specific recovery actions are more restricted.

For systems which have more intelligent capabilities, other methods which take into account quantitative information may be used. Such factors include, but are not limited to, severity of potential collisions, appropriate responses, temporal proximity, driver response time and distance, consequence probability, message redundancy, perceptual difficulty, warning validity, causal relationships, and informativeness of the warning. The trade-off between these items must be defined such that the warning which requires the most immediate action or minimizes the hazard most will be presented first.

[*See specific 2.3.2 comments in Appendix A*]
[*See Review and Discussion Issue #9 in Appendix B*]

2.3.3 RULES FOR DISPLAY OF MULTIPLE WARNINGS.

The following display rules should be employed when multiple, simultaneous warning conditions exist:

a. All crash avoidance warnings, regardless of their priority, should be presented simultaneously by means of a visual display.

b. Only the highest priority warning in effect should be presented by means of an acoustic or tactile display.

c. 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.

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. An imminent crash warning indicates the presence of a hazardous situation requiring immediate attention and a quick control response from the driver. Any delay in the perception of an imminent warning and subsequent control response increases the probability that a collision will occur. This is particularly critical with regard to imminent crash avoidance warnings where the time available to avoid the crash is limited to seconds or fractions of seconds. When two imminent crash warnings are presented in the auditory domain a cue is required to provide the driver with clear information that the original crash situation has been responded to and that a new one exists. Without a clear indication that the original signal is no longer in effect and that a new one has taken effect, the driver may continue to attempt to solve the original crash situation and will not provide the desired behavior for solving the new crash problem.

[*Specific 2.3.3 comments in Appendix A*]
[*See Review and Discussion Issue #10, Comment 10 in Appendix B*]

2.3.4 AUTOMATIC TERMINATION OF WARNINGS.

The device that triggers a warning should terminate the warning automatically once the triggering condition no longer exists. Based on driver response to the situation, other automatic and manual methods for terminating warnings for specific devices may be permissible. Sections 3 through 6 present examples for specific devices.

Most human factors standards (NUREG 0700, MIL-STD-1472D, DOE-STD-HFAC) require that the operator either manually acknowledge or automatically terminate warnings, or both. In a hazardous driving situation, the driver has only a few seconds, at most, to react to the warning to avoid a collision. By requiring the driver to manually silence the warning, an additional unnecessary task is placed on the driver during a high workload situation. Therefore, the device should provide an automatic termination of the warning when the hazard no longer exists. Terminating warnings automatically based on driver response to the situation should be considered on a device-by-device basis, since initiation of a response in reaction to a warning may not always constitute an adequate reaction to the warning.

[*See specific 2.3.4 comments in Appendix A*]

2.3.5 COMPATIBILITY OF WARNING TO DRIVER RESPONSE.

Warnings should be presented in a manner that is compatible with the driver's desired vehicle control response. The warning should induce an orienting response, where appropriate, causing the driver to look in the direction of the hazard. The warning should adequately capture the driver's attention without startling the driver.

The onset of an intense stimulus, whether visual, auditory, or tactile, will elicit an orienting response from the operator. This response should be compatible with the desired action. The warning should not induce the driver to look in a direction other than that to which attention should be directed in order to avoid a crash. Where the operator response is not known, caution should limit use of a given signal. For example, a vibrotactile signal from the accelerator pedal may cause drivers to look down at the pedal, rather than at the road ahead, and/or it may induce braking. Application of this type of warning for a given situation should be avoided unless the compatibility of the reaction is known.

[*See specific 2.3.5 comments in Appendix A*]
[*See Review and Discussion Issue #6, Comment 3 in Appendix B*]

2.3.6 PREVENTION OF FALSE/NUISANCE WARNINGS.

False warnings (i.e., those triggered by an inappropriate stimulus event) and nuisance warnings (i.e., those triggered by an appropriate stimulus event under conditions that are not useful to the driver) should be minimized without seriously degrading the hazard detection performance of crash avoidance warning devices. In addition to the false/nuisance alarm rate for a single device, the combined rate for an entire warning system should be considered when multiple devices are in a vehicle. The following methods may be used to reduce the number of false/nuisance warnings:

a. Deactivating a warning device automatically when it is not needed during a particular driving situation (i.e., requiring the shift lever to be in reverse gear to place the backup warning device in the active mode).

b. Allowing 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.

c. Presenting a warning only after a target or critical situation has been detected as continuously present for some specified minimum time.

d. Mitigating the annoyance of false/nuisance warnings by allowing the driver to reduce warning intensity or volume.

False/nuisance warnings are known to have adverse effects on human performance and confidence in warning systems. For this reason, most human factors design standards and guidelines state that false/nuisance alarms should be minimized (MIL-STD-1472D, DOE-STD-HFAC). However, in most instances, no specific suggestions are made to reduce their occurrence to some tolerable level. This tolerance level is presently unknown for crash avoidance warning systems in highway vehicles.

There are two general issues related to the acceptable level for false/nuisance warning rates which must be taken into account. One issue is the equivalent tolerability of different types of false/nuisance warnings. The other issue is the combined effect of false/nuisance warnings from multiple devices. Information is lacking for both of these issues.

There are a variety of categories of warnings that are not useful to the driver, which may, therefore, cause annoyance, degraded warning validity, and poor user acceptance. At the most general level, these can be distinguished as "false warnings" and "nuisance warnings." The false warning is one in which the warning is triggered by an inappropriate stimulus event. Examples might include triggering due to rain, wind, electronic noise, or glare. Nuisance warnings, in contrast, are triggered by an appropriate stimulus event under conditions that are not useful to the driver. For example, if a device is intended to identify obstacles ahead of the vehicle, and responds to fixed objects along the roadway of a horizontal curve that the vehicle is approaching, the warning is not appropriate. In this situation, the warning system simply cannot discriminate the intended path of the vehicle. Similarly, warnings may be inappropriate because assumptions about driver, vehicle, or environmental characteristics (e.g., reaction time, braking distance) make the timing of the warning inappropriate. There may also be situations where the driver is aware of the situation which results in a warning (i.e., intentionally staying close to the rear of the lead vehicle). Because the operator is already aware, the warning is redundant and not useful. Each of these types of false and nuisance alarms may have some negative effect on driver performance and product acceptance. However, the relative frequency, and importance, of each type of unwanted warning is not known, and rules for combining the rates cannot be specified.

The second issue of concern for defining the acceptable false/nuisance warning rate for a crash avoidance warning system is the distinction between device-specific false/nuisance warning rates and system-wide false/nuisance warning rates. It may be possible to specify some optimal design for a given warning device such that the trade-off between sensitivity and false/nuisance warnings is optimized. However, this does not necessarily mean that if several such devices are present in a vehicle as a warning system, that the overall rate of undesired warnings will be acceptable. The system-wide rate would be a summation of all the individual device rates, and may be too high. Existing literature appears to provide no guidance for dealing with this. It may also be the case that the "combination rules" depend on such factors as whether the individual devices share a common output, and whether warnings are viewed as more distinct by the driver. Pending further research, it can only be recommended that multiple device warning systems be thoroughly tested *as a system* to determine an acceptable level of performance under realistic conditions.

It is suggested that by requiring the sensed object or hazardous situation to be persistently detected for some minimum period of time, false/nuisance warnings can be reduced. It must be noted, however, that an overly stringent criterion will delay the warning and, thus, driver reaction. The minimum target capture time should not preclude recognition of smaller targets, such as motorcycles or pedestrians. No minimum target detection time is specified here because this parameter will be related to the specific type of warning device, the size and shape of the detector field, as well as the sensor technology and algorithms employed.

[*See specific 2.3.6 comments in Appendix A*]
[*See Review and Discussion Issue #6, Comment 4 in Appendix B*]
[*See Review and Discussion Issue #7, Comment 4 in Appendix B*]
[*See Review and Discussion Issue #11 in Appendix B*]
[*See General Comments in Appendix C*]

2.4 AUDITORY DISPLAYS.

Auditory displays include both acoustic and speech displays. When used in conjunction with visual displays, auditory displays provide the redundancy necessary for crash avoidance warning systems. Auditory displays are most effective if they are reserved for imminent crash avoidance warnings, but they may also be effectively used for cautionary warnings for certain devices. Auditory warnings should not be used for status displays.

2.4.1 CHARACTERISTICS OF AUDITORY IMMINENT CRASH AVOIDANCE WARNINGS.

Auditory displays are the recommended mode of display for imminent crash avoidance warnings. The auditory display for imminent crash warnings should be distinctive and reserved only for crash avoidance warnings. The warning may be either an acoustic signal or a voice message, but the imminent crash avoidance warning should be consistent across crash avoidance devices. In the absence of a standard acoustic and voice display, refer to Sections 2.4.5 and 2.4.6 for recommendations for acoustic and speech displays, respectively.

Numerous studies support the superiority of auditory displays in terms of alerting value and reaction time (Horowitz & Dingus, 1992; Lilliboe, 1963; Teichner, 1954), particularly in situations in which alerting the individual is of prime importance. In an imminent crash avoidance situation, the alerting value of a display and the reaction time to a display are overriding concerns. Therefore, auditory displays are recommended. Although tactile warnings are permitted as an alternative to an auditory mode of display, the current state of knowledge regarding tactile warning displays suggests that auditory warnings should be favored, except where it is clearly demonstrated that the tactile display is as effective as an auditory display.

[*See specific 2.4.1 comments in Appendix A*]
[*See Review and Discussion Issue #14 in Appendix B*]
[*See General Comments in Appendix C*]

2.4.2 CHARACTERISTICS OF AUDITORY CAUTIONARY CRASH AVOIDANCE WARNINGS.

Auditory displays should not be used for cautionary crash avoidance warnings unless the advantages of using such displays outweigh the disadvantages.

There is a design trade-off between the advantages of auditory displays, which include superior alerting capabilities and reduced reaction times, and their disadvantages, which include their potential for annoying the driver in the case of frequent false or nuisance alarms (Butler, Manaker, and Obert-Thorn, 1981; Randle, Larsen, and Williams, 1980) and the possibility that such displays may create auditory clutter (Patterson, 1982). In addition, auditory warnings may not be perceived in noisy driving environments. Therefore, the designer must consider these trade-offs when deciding whether an auditory display is appropriate for cautionary crash avoidance warnings. Because of the possibility for multiple crash avoidance warning devices in the vehicle, the potential for annoyance and intrusiveness is increased, due to an increase in the rate of false and nuisance alarms. Visual cautionary warnings are preferred for any device except where important advantages of cautionary auditory displays can be demonstrated, and user acceptance is high.

[*See specific 2.4.2 comments in Appendix A*]
[*See General Comments in Appendix C*]

2.4.3 AUDITORY DISPLAYS FOR STATUS INFORMATION.

Auditory displays should not be used to provide status information.

In order to preserve the saliency of auditory signals for warnings, they should not be used to convey status information. Additionally, drivers will quickly adapt to the auditory signals or, on the other hand, may turn them off. The resulting adaptation will decrease the effectiveness of the warning signal.

2.4.4 SOUND SOURCE LOCATION.

The apparent source of an auditory warning should be consistent with the direction of the hazard.

Because of rapid advances in auditory display technology (e.g., 3-dimensional auditory displays), the location of the sound source conveying auditory information is less important than the location from which the sound *appears* to emanate.

2.4.4.1 Cuing for Directional Hazards.

Devices which provide auditory warning directional information should locate the sound source such that the warning appears to emanate from the position in the vehicle which is

closest to the location of the target or crash situation which triggered the warning.

Auditory warnings can be used to provide directional information because humans are, in general, very good sound localizers (McFadden and Pasanen, 1976; Mills, 1958). Three-dimensional auditory display technology is beginning to mature and may soon be available in a variety of applications, allowing for the presentation of auditory information at virtually any location. If such technology is not cost-effective, auditory warning directional information can be conveyed through, for example, the use of the four stereo speakers in the vehicle or through the appropriate location within the vehicle of the crash avoidance warning device speakers (see Section 2.4.4.3 for limitations on use of displays directly ahead of or behind the driver).

[*See specific 2.4.4.1 comments in Appendix A*]

2.4.4.2 Cuing for Non-Directional Hazards.
The auditory warning for non-directional hazards should be presented such that the driver's attention is directed to the driver's line of sight of the roadway ahead or toward a visual display that specifies the nature of the hazard.

Non-directional hazard warnings should serve to heighten the driver's awareness of the driving situation, and should not be confused with directional crash avoidance warnings. By directing the driver's attention to the roadway ahead or to a visual display, the tendency for confusion with directional crash avoidance will be reduced, while still increasing the driver's general awareness of the hazardous situation.

2.4.4.3 Auditory Displays In Front of and Behind the Driver.
Auditory warnings that are presented to the front or rear of the driver should not be presented in the median plane (i.e., the plane perpendicular to the horizontal plane which passes through the driver's ears).

Although humans are generally good sound localizers, they have difficulty identifying sounds directly above, in front of, or behind them, without some head movement. As a result, front-to-back perceptual confusions occur frequently (Blauert, 1969/1970; Makous and Middlebrooks, 1990). However, even slightly offsetting the location of such sounds by a few degrees to the right or left eliminates this problem because of the acute human perceptual sensitivity to inter-aural time differences (McFadden and Pasanen, 1976).

2.4.5 CHARACTERISTICS OF ACOUSTIC DISPLAYS.
Acoustic displays (i.e., all auditory displays except speech displays) may be used for

imminent and cautionary crash avoidance warnings. Acoustic displays may be used to alert the driver that a crash situation exists, assist the driver in locating the target or crash situation, and convey hazard proximity.

[*See specific 2.4.5 comments in Appendix A*]
[*See Review and Discussion Issue #7, Comment 2 in Appendix B*]

2.4.5.1 Coding of Levels of Warning.
Acoustic displays used for imminent crash avoidance warnings should convey more urgency than other types of acoustic crash avoidance warnings present in the vehicle. The following characteristics may be used to differentiate imminent from cautionary acoustic crash avoidance warnings:

IMMINENT	CAUTIONARY
high signal (or pattern) repetition rate	**low signal (or pattern) repetition rate**
high intensity	**low intensity**
high fundamental frequency	**low fundamental frequency**
large frequency oscillations within auditory patterns	**small frequency oscillations within auditory patterns**

Edworthy, Loxely, and Dennis (1991) enumerate the sound characteristics that increase the perceived urgency of a warning signal, and the preceding guideline is largely based on their work. Additional work conducted by Peio and Dolan (1992) supports this recommendation.

[*See specific 2.4.5.1 comments in Appendix A*]
[*See General Comments in Appendix C*]

2.4.5.1.1 Intensity Coding.
Intensity coding should not be used to distinguish among the levels of warning of a crash avoidance warning device or system.

Intensity coding is generally not recommended because people are poor judges of absolute levels of intensity (Van Cott and Kinkade, 1972). Although imminent crash avoidance warnings may be conveyed at a greater intensity than cautionary crash avoidance warnings, other auditory characteristics besides intensity should be used to code the level of warning.

2.4.5.1.2 Duration Coding.
Duration coding is not recommended for auditory crash avoidance warning displays. Pattern of tones may be used (see Section 2.4.5.8).

Drivers' inabilities to judge absolute signal duration in the absence of a comparison tone will require that duration differences be quite large. Because of this, the overall time required to present the signal would be so long as to delay driver response.

2.4.5.2 Fundamental Frequencies.
Sounds having fundamental frequencies between 500 and 3000 Hz are recommended for acoustic crash avoidance warnings. If frequency is used as a code to distinguish among the levels of warning of a device or system, the fundamental frequencies chosen should be broadly spaced over the 200 to 3000 Hz range (e.g., 200, 1600, and 2800 Hz instead of 200, 300, and 400 Hz). The frequencies chosen should be those least subject to masking by ambient noise. In accordance with Section 2.4.5.1, if frequency is used to code levels of warning, imminent crash avoidance warnings would have the highest fundamental frequency.

Fundamental frequency values are well established in the auditory warning literature, (VanCott and Kinkade, 1972; Morgan, Cook, Chapanis, and Lund, 1963; MIL-STD-1472D; NUREG 0700). However, both Veitengruber, Boucek, and Smith (1977) and Berson, Po-Chedley, Boucek, Hanson, Leffler, and Wasson (1981) caution that frequencies should be chosen with due consideration of the noise characteristics of the operational environment.

[*See specific 2.4.5.2 comments in Appendix A*]
[*See General Comments in Appendix C*]

2.4.5.3 Spectral Characteristics.
If a single sound is used for a crash avoidance warning, a complex sound should be used, as opposed to a pure sinusoidal waveform. Variations in spectral characteristics may be used to code levels of warning.

Complex sounds are more easily identified than pure tones. Pure tones also tend to be annoying to the listener. Because complex sounds contain a variety of perceptual cues, it is easy to create numerous signals that can be easily differentiated and absolutely identified. Pure tones, in contrast, are less "rich" and can be identified only on the basis of their frequency (Van Cott and Kinkade, 1972; Morgan, Cook, Chapanis, and Lund, 1963; MIL-STD-1472D; NUREG 0700).

2.4.5.4 Default Warning Intensity.
At the driver's ear, default intensity values for acoustic warnings should be at least 20dB, but no more than 30dB, above the masked threshold based on ambient noise for relatively noisy operating conditions.

Antin, Lauretta, and Wolf (1991) recommend that acoustic warnings be at least 20 dB above masked threshold, but should not exceed the masked threshold by more than 30 dB. The perceived intensity of sound depends on a number of factors, most notably the location of the sound source with respect to the driver's ear. Therefore, optimum default intensity values may differ depending on the location of the sound source and any obstructions that block the path of the sound.

[*See specific 2.4.5.4 comments in Appendix A*]

2.4.5.5 Onset and Offset Rates.
The onset rate for sounds or tones used in crash avoidance warnings should be rapid enough to alert the driver, but not so rapid as to induce severe startle effects. Onset rates of greater than 1 dB/msec but less than 10 dB/msec are recommended. The offset rate should be equal to the onset rate.

According to Woodson and Conover (1964), sounds with onset rates less than 1 dB/msec are perceived as continuously rising and produce little or no startle effects. Sound with onset rates of 10 dB/msec appear instantaneous and will produce moderate startle responses.

2.4.5.6 Warning Duration.
A single sound or tone used as a crash avoidance warning signal should be between 200 and 500 msec in duration. If complex tones, as opposed to pure tones, are used, durations near the bottom of this range (e.g., 200-300 msec) are recommended.

Tones less than 200 to 500 msec in duration are not perceived as very loud, and are easily missed in a noisy environment (Sanders and McCormick, 1993). There is, in addition, a trade-off between intensity and duration. The shorter the duration of the tone, the greater its intensity needs to be (Sanders and McCormick, 1987). It is important from a reaction time perspective to keep the off-time of the repetition cycle short since the driver is not receiving useful information during the off period.

[*See specific 2.4.5.6 comments in Appendix A*]

2.4.5.7 Warning Repetition.

If a single sound or tone is used as a crash avoidance warning signal, it should be repeated for as long as the crash avoidance warning condition exists, or until the system or device recognizes some corrective action on the part of the driver. The criterion that applies depends on the type of device, as noted in the specific guidelines sections.

[*See specific 2.4.5.7 comments in Appendix A*]

2.4.5.8 Use of Auditory Patterns as Acoustic Crash Avoidance Warnings.
Continuously repeating auditory patterns, as opposed to repeating single tones or sounds, may be used for acoustic crash avoidance warning displays, provided they are of short duration or cycle time. Such patterns should be easily learned and perceived and be absolutely identifiable by the driver.

Limited research exists concerning the use of complex auditory patterns, as opposed to individual sounds or tones, to convey warning information. Their potential is only now being investigated (May, 1993), and use of complex auditory patterns in the future should not be ruled out.

2.4.5.9 Conveying Time- or Distance-to-Collision Information.
Acoustic displays may convey time- or distance-to-collision information (i.e., graded warnings), if such information is provided for a particular crash avoidance warning device. The following means of conveying this information through acoustic displays are recommended:

a. **Warning repetition rate increases as time- or distance-to-collision decreases; repetition rate decreases as time- or distance-to-collision increases.**

b. **Fundamental frequency of warning tones increases as time- or distance-to-collision decreases; fundamental frequency of warning tones decreases as time- or distance-to-collision increases.**

c. **Intensity of warnings increases as time- or distance-to-collision decreases; intensity of warnings decreases as time- or distance-to-collision increases.**

These manipulations of acoustic warnings are based on the work of Edworthy, Loxely, and Dennis (1991). As time- or distance-to-collision decreases, warnings can be made to sound more urgent through the suggested manipulations. Likewise, as the collision threat decreases, the warnings are perceived as less urgent.

2.4.6 CHARACTERISTICS OF SPEECH DISPLAYS.
Speech warning displays should be highly intelligible, but readily distinguishable from the

normal human voice. Speech displays may be used to present imminent and cautionary crash avoidance warnings. They should serve an alerting function and may also provide directional information. Speech displays are not recommended for providing time- or distance-to-collision information.

Drivers may find it difficult to discriminate digitized speech from both passenger and radio speech present in the vehicle. Therefore, the voice employed for speech warnings, whether synthesized or digitized, should be readily discernible from the human voice.

Generally, more time is required to deliver a speech message than to alert the driver through other modes. For this reason, speech displays are not recommended for presenting specific information of a dynamic nature. Acoustic displays, which can cycle quickly, are capable of providing such information more succinctly than speech displays.

[*See specific 2.4.6 comments in Appendix A*]

2.4.6.1 Message Length.
Speech warnings should be as brief and concise as possible (e.g., one to three words).

There is limited time available for the presentation of speech messages in crash avoidance situations. Therefore, messages must be short, generally between one and three words. However, in applications where time availability is not a critical factor, longer messages are preferred, because they allow the listener to accommodate to the synthetic speech, thereby increasing its intelligibility. Although this "ramp-up" time is short, it is normally desirable in other contexts in which time pressure is minimal (Rosson, 1985; Thomas, Rosson, and Chodorow, 1985).

2.4.6.2 Vocabulary.
The vocabulary used for speech messages should be limited in size, and should consist of words which can be easily discriminated from one another. If sufficient time is available, polysyllabic words are recommended over monosyllabic words.

Since messages must be brief, and the driver will have little time or opportunity to adapt to synthetic speech, the vocabulary must be limited. Because short messages will be presented in isolation, the driver will not be able to identify the words based on context cues. The vocabulary, therefore, should consist of words that are easily discriminated by the driver. Hart and Simpson (1976) have demonstrated that polysyllabic words are more easily recognized than monosyllabic words in some contexts and environments.

2.4.6.3 Message Content.

The content of speech messages should be limited to that which alerts the driver to the crash avoidance situation and directs the driver's attention to its location. Imminent and cautionary speech messages should be differentiated by their message content. Stronger language should be used for imminent than for cautionary warning messages.

Auditory displays, generally speaking, have good alerting capabilities. Given the limited time available to convey crash avoidance messages via the speech mode, the alerting function should be exploited. Because direction can be conveyed easily with minimal vocabulary or through the location from which the speech appears to emanate, directional information may also be conveyed. More complex forms of information (e.g., time- or distance-to-collision) should not be incorporated into speech messages.

There are few recommended ways in which speech displays can be coded to differentiate imminent and cautionary conditions. The most obvious way is through differences in content (i.e., "Danger" for imminent warnings; "Caution" for cautionary warnings). Other means of indicating urgency have been explored, including speech rate and voice pitch (Simpson and Marchionda-Frost, 1984), but testing of candidate frequencies and rates would be needed before such techniques could be recommended for use in crash avoidance warnings.

[*See specific 2.4.6.3 comments in Appendix A*]

2.4.6.4 Message Presentation.

The speech delivery system used to convey crash avoidance warnings should be one which demonstrates a high level of intelligibility in tests using isolated words. Candidate systems should demonstrate high intelligibility of the specific vocabulary to be used in the warnings.

Due to the small vocabulary and limited message length, intelligibility measures based on conversational speech intelligibility will be less relevant in choosing a system than measures based on the intelligibility of isolated words (Moore, 1985). In addition, synthetic speech systems, which are largely rule-based, differ from one another with respect to the pronunciation and intelligibility of individual words. Although many systems exist which have merited high scores on intelligibility tests, a confirmation of the specific vocabulary to be used is, nevertheless, recommended. Studies (Nixon, Anderson and Moore, 1986) also indicate that higher quality synthetic speech systems are generally more intelligible in noisy environments.

[*See specific 2.4.6.4 comments in Appendix A*]

2.4.6.5 Message Repetition.
A given speech warning should be presented no more than three times for a given crash avoidance warning situation, regardless of the duration of the situation. Repetitions should occur in immediate succession. If the duration of the crash avoidance condition is less than the time required to deliver the three presentations of the speech message, the speech message should be terminated when the crash avoidance situation terminates.

Voice messages should not be repeated numerous times because of their tendency to irritate the driver and upset passengers. Voice messages will be more disturbing, particularly to passengers, than any other type of warning, if repeated frequently in succession. In addition, the potential for embarrassing the driver and creating a panic situation is greater for speech displays than for other displays. The three-presentation limit is based on the Traffic Collision Avoidance System (TCAS) used in aviation, which also provides two and, for some messages, three presentations of collision avoidance warnings and instructions (Federal Aviation Administration, 1990).

2.4.6.6 Use of Multiple Languages for Speech Warnings.
Speech technology used for crash avoidance warning devices and systems may incorporate multiple language options. Crash avoidance warning vocabularies and messages should be developed and tested separately for each language to be represented within the system or device.

Crash avoidance warning device or system developers cannot assume that messages developed for use by the English-speaking population can be translated directly into other languages. Nor can they assume that words that are highly discriminable in English will be highly discriminable in other languages. Vocabularies and speech messages must be developed and tested separately for each language to be employed in a crash avoidance warning application.

2.4.6.7 Voice Characteristics.
The voice characteristics of speech displays should be such that the synthetic messages can be easily differentiated from other speech in the vehicle (e.g., passengers talking, or speech on the radio). The voice characteristics should yield a clearly mechanical, authoritative, voice, but not an unpleasant (e.g., tinny) one.

Speech messages must be differentiable from other speech in the vehicle. In an aircraft situation, for example, in which most of the flight crew is male, female synthetic speech messages are often employed. This reasoning, however, is not as applicable in the driving environment. The most obvious way to differentiate synthetic speech is to make it sound clearly non-human. A number of researchers (Brown, Bertone, and Obermeyer, 1986) advocate doing this. Gardner-Bonneau (1989) found, in a telephone application for American Express, that the more rigid and mechanical a voice sounded, the more commanding it appeared to be and the more compliant listeners were with respect to instructions presented in synthetic speech. It is also true, however, that listeners may reject synthetic speech if it sounds too robotic and stilted. Hence, care must be taken to ensure that the voice characteristics achieve a perception of authoritativeness, without a cold, robotic tone to the message.

[*See specific 2.4.6.7 comments in Appendix A*]

2.4.6.8 Speech Warning Presentation Rate.
A speech warning rate of 156 words per minute is recommended, although slightly higher rates (up to 200 words per minute) may be used (e.g., 2 to 3 words per second).

Simpson and Marchionda-Frost (1984) found an optimal speech rate of 156 words per minute, although the pilots in their study had no difficulty understanding synthetic speech at 178 words per minute, the highest rate used in the study. Conversational speech can be comprehended at more than twice that presentation rate, with minimal adaptation time (Goldhaber and Weaver, 1968). However, the results of one recent study (Tun, Wingfield, Stine, and Arthur, 1992), which employed synthetic speech rates from 140 to 280 words per minute, indicated that older adults' immediate memory performance was depressed when speech rates were very fast. Therefore, a rate of 156 words per minute is recommended. Rates slightly higher than this are acceptable.

2.4.6.9 Speech Warning Intensity.
The speech warning should be loud enough to be clearly intelligible in all anticipated operating environments.

The appropriate intensity level for speech warnings depends on the noise level in the ambient environment, the distance of the speech source from the driver, characteristics of the speech signal, the design of the speech system, and other factors. It is quite possible that data and recommendations concerning the perception of natural speech in noise (Kryter, 1972; Peterson and Gross, 1978) would apply to synthetic speech as well, but no existing studies make this comparison.

2.4.6.10 Use of an Alerting Tone Preceding Speech Messages.
An alerting tone should not be used preceding voice messages unless its benefits in the crash avoidance context can be demonstrated.

A number of studies (Bertone, 1982) and standards (MIL-STD-1472D) recommend the use of an alerting tone preceding speech warning messages, because the tone can speed response to the speech message to some extent.

However, such tones may not be appropriate in the crash avoidance context because of the limited time available to present crash avoidance information. The presentation of an alerting tone and a pause prior to the presentation of the speech warning would add approximately one-half second to the presentation. Furthermore, the facilitation of the alerting tone may be minimal, given that messages are brief, repeated, and easily distinguished from other speech in the vehicle. Simpson and Williams (1980), Wheale (1980), and Thomas, Rosson, and Chodorow (1984) indicate that an alerting tone is not needed if synthetic speech is used only for warnings in the operational environment. Even if this is not the case, these authors indicate only that an alerting tone *might* be necessary. TCAS, for example, does not employ an alerting tone prior to speech messages (Federal Aviation Administration, 1990). The benefits of an alerting tone in this application remain untested and unverified. Clearly the ability of a particular voice message to initiate the proper response in the time available must be verified for each device.

[*See specific 2.4.6.10 comments in Appendix A*]

2.4.7 CONTROL OF AUDITORY DISPLAY INTENSITY.

This section presents guidelines for the control of the intensity (volume) of auditory crash avoidance warning displays.

[*See specific 2.4.7 comments in Appendix A*]

2.4.7.1 Automatic, Adaptive Control of Auditory Display Intensity.

If possible, the volume of auditory warning displays should be adjusted automatically based on the noise conditions existing within the vehicle.

Antin, Lauretta, and Wolf (1991) conducted both driver detection and preference studies of sound intensity for auditory in-vehicle displays. They found that the sound level necessary for detection when driving at a high speed, for example, was greater than that for a low speed. In addition, they found that drivers prefer sound intensities greater than those that would be established based solely on detection data. It should also be noted that noise levels within the vehicle vary greatly based on the type of the vehicle (e.g., luxury cars vs. heavy commercial trucks). Therefore, automatic adaptive control of intensity, taking into account such data, is recommended.

[*See specific 2.4.7.1 comments in Appendix A*]

2.4.7.2 Interruption of Other Auditory Displays.

Crash avoidance warnings should automatically interrupt other inputs to the speakers when warnings are displayed.

Speech or music coming from the stereo speakers could effectively mask a crash avoidance warning emanating from the same location. In such a case, the volume of other auditory inputs to the vehicle should be automatically decreased whenever auditory warnings are presented to the driver.

2.4.7.3 Manual Adjustment of Auditory Display Intensity.
To accommodate drivers with hearing impairments, and to accommodate a wide variety of driving environments, the capability to adjust the intensity of auditory crash avoidance warning displays must be provided, even if automatic, adaptive volume control is provided.

The capability to adjust the volume will allow the driver to avoid annoyance in the case of frequent false alarms created, for example, under heavy traffic conditions. In addition, it will allow those drivers with hearing impairments, and\or those in noisy driving environments, to increase the volume to a readily perceptible level.

[*See Review and Discussion Issue #10 in Appendix B*]

2.4.7.3.1 Minimum Intensity.
The minimum intensity to which a system or device is adjustable must still be readily perceptible to the non-hearing-impaired driver. Devices should be tested to determine the appropriate value for minimum intensity.

If the display intensity can be reduced to inaudible levels, drivers may fail to readjust the volume to an audible level when appropriate. The existence of a minimum perceptible signal helps to ensure that drivers will maintain awareness of the system or device. A minimum value cannot be defined in these Guidelines because the desirable minimum depends on a number of factors, including the nature of the warning display (e.g., fundamental signal frequencies), its location within the vehicle, the potential for physical obstruction of the speakers created by the presence of passengers within the vehicle, and ambient noise conditions. Therefore, testing to determine the appropriate minimal intensity level for a specific crash avoidance warning device or system is recommended.

[*See specific 2.4.7.3.1 comments in Appendix A*]

2.4.7.3.2 Maximum Intensity.
Auditory signal intensities should not exceed a maximum of 115 dBA.

The Occupational Safety and Health Act permissible daily noise exposure limits allow up to a 115 dBA sound level for a duration of 0.25 hours per day (Woodson, Tillman, and Tillman, 1992). Although this intensity would undoubtedly be too great for most driving environments, it should be remembered that this is the maximum allowable intensity setting for the volume.

2.4.7.3.3 Master Intensity Control.

A master control for auditory display intensity, supplementary to the individual intensity controls, may be provided for a crash avoidance warning system.

A master intensity control would allow the driver to adjust the intensity for the system in an all-or-none fashion, rather than forcing him/her to adjust intensity separately for each warning device within the system. This may be particularly desirable when the driver first starts the vehicle's engine, if he/she wishes to simultaneously change the volume for different devices within the system from the original default settings. However, a master control is not intended as a substitute for the individual volume controls.

[*See specific 2.4.7.3.3 comments in Appendix A*]

2.5 VISUAL DISPLAYS.

This section presents guidelines for the use of visual warning displays and visual status indicators in crash avoidance warning devices and systems. Visual warning displays may provide descriptive information and are recommended for most levels of warning. Refer to the specific guidelines sections for specific device recommendations.

It is likely that visual displays will be the prominent mode of presentation for crash avoidance warnings, at least in the near-term. Reasons for this include the fact that auditory displays cannot be used alone because of possible masking of the warning in noisy driving environments and the need to accommodate individuals with hearing impairments, as well as the fact that the development of tactile displays lags behind that of other types of display modes. Furthermore, because both auditory and tactile displays are temporal in nature, they do not provide the best means of presenting integrated information in the event of multiple, simultaneous crash avoidance situations. For some specific devices which do not rely specifically on target detection or directional cues (e.g., driver alertness monitoring devices, low road friction devices), visual warning displays may provide descriptive information which identifies the nature of the hazard. Therefore, visual displays are recommended for most levels of warning for most types of warning devices.

Visual displays are divided into two types, primary and secondary displays. The primary display, which is a required display, contains that information which is critical to capturing the driver's immediate attention, identifying the nature of the hazard, and directing the driver's attention to the hazard. The secondary display, which is optional, can provide additional information to the driver, such as time- or distance-to-collision, and may be useful in avoiding potential crash situations.

Three categories of visual display information should be utilized: imminent crash avoidance warning, cautionary crash avoidance warning, and operational status information. The Guidelines contained in this section are intended to ensure that all three levels of information are available when they are needed and are easily distinguishable from each other. This will allow the driver to quickly and accurately assess the driving situation and respond appropriately in a potential crash situation.

[*See specific 2.5 comments in Appendix A*]

2.5.1 PRIMARY AND SECONDARY VISUAL DISPLAYS.

This section presents general design guidelines for primary and secondary visual displays. Primary visual displays should serve as the main visual display of the warning device. Secondary visual displays are optional. Secondary displays can be made available to the driver to provide additional information concerning the location or nature of the hazard (e.g., distance- or time-to-target, iconic representation of hazard location in relation to the vehicle).

2.5.1.1 Primary Visual Displays.

Primary displays should immediately and reliably capture the driver's attention and direct the driver to the direction or nature of the hazard. These displays should be simple and should be more conspicuous than secondary displays.

2.5.1.1.1 Simplicity.

Simple indicators should be used as primary visual displays, providing only the information necessary for the driver to resolve the crash situation. Alphanumeric displays, complex icons, and trend information (e.g., graphical information, etc.) should be avoided.

The major function of primary visual displays is to capture the driver's attention and to direct the driver's attention to the hazard. Displays that are simple and uncluttered constitute the most effective means of accomplishing these goals. The driver should be able to assimilate visually displayed information with minimal glance times. Because complex displays require excessive eye-off-the-road time, slow the decision-making process, and increase overall response time, they should not be used in primary visual displays. Additional information, such as distance- or time-to-target or relative location indicators, should not be presented in the primary display itself. It should be noted, however, that directional cues should be conveyed by the location and placement of the primary display (see Section 2.5.1.1.2).

[*See specific 2.5.1.1.1 comments in Appendix A*]

2.5.1.1.2 Location.
Primary display visual warnings should be located within 15 degrees of the driver's expected line of sight in a given crash avoidance warning situation. Recommended locations for specific warning devices are presented in the specific guidelines sections. For directional warning situations, primary visual displays should be located such that they draw the driver's attention to the direction of the hazard. Displays for non-directional warnings (e.g., low road friction) should be located within 15 degrees of the driver's line of sight of the roadway ahead. Primary visual displays should be entirely visible at all times. Primary visual displays should not be obscured by other visual displays or structures within the vehicle (e.g., steering wheel, etc.).

A driver's optimum field-of-view is within 15 degrees of the normal line of sight (MIL-STD-1472D). For crash avoidance warnings, the "normal" line of sight will vary according to the specific driving situation (i.e., forward obstacle vs. backup warning situations). Directional warnings (i.e., warnings based on detection of an object or obstacle in the current or intended pathway of the vehicle) should be presented within 15 degrees of the driver's expected line of sight for the specific driving maneuver. Specific recommendations for some devices can be found in the specific guidelines sections. Non-directional warnings (i.e., warnings based on hazardous driving conditions, such as low road friction) should be presented within the driver's line of sight of the roadway ahead.

[*See specific 2.5.1.1.2 comments in Appendix A*]

2.5.1.1.3 Manual Adjustment of Visual Display Intensity.
A single master control should be provided to permit the driver to simultaneously adjust the intensity of all visual displays for a specific device or for an integrated system. Intensity adjustment should be restricted such that at the dimmest setting the status display remains visible and the warning displays can be readily perceived by the driver. At all intensity settings, the requirements in Section 2.5.2 apply.

Since the in-vehicle ambient illumination will vary depending on such variables as the time of day and because of individual perceptual capabilities and preferences, the driver should be given the opportunity, as in current dash displays, to adjust the intensity of the status indicators and warning indicators. Adjustability should be restricted to prevent reducing intensity to an imperceptible level under the anticipated range of driving conditions.

[*See specific 2.5.1.1.3 comments in Appendix A*]
[See Review and Discussion Issue #10 in Appendix B]

2.5.1.2 Secondary Visual Displays.
Secondary displays should be less conspicuous than primary displays and should not distract the driver's attention from the primary display. Secondary visual displays should not provide flashing indicators.

[*See specific 2.5.1.2 comments in Appendix A*]

2.5.1.2.1 Directly Usable Information.
A driver should not be required to transpose, compute, interpolate, or translate displayed crash avoidance warning information.

Requiring the driver to carry out mental manipulations in order to obtain warning information will increase cognitive demands and, therefore, response time (MIL-STD-1472D).

2.5.1.2.2 Display Legibility.
Crash avoidance warning displays should be legible at a glance. Display characters (e.g., alphanumerics, geometric shapes) should subtend a minimum visual angle of at least 12 minutes of arc.

The driver has a very limited time to react to a warning situation. This time should not be spent processing information from complicated visual displays. Symbols, icons, and any other graphics used in crash avoidance displays must be extremely simple and intuitive. The symbols must be of sufficient size that the driver can recognize and interpret them with a single glance at the display. Sanders and McCormick (1993) recommend a minimum visual angle of 12 minutes of arc. This recommendation, however, should be used as minimum, taking into account such factors as the distance of the display from the driver, the vibratory environment of the vehicle, criticality of the display information, and ambient illumination. Testing should be conducted for specific displays to ensure that the display is legible for 95% of the expected driving population.

[*See specific 2.5.1.2.2 comments in Appendix A*]

2.5.1.2.3 Icons/Pictographs.
Icons/pictographs used in warning displays should be intuitive and should not require excessive perception time. Icons/pictographs should be meaningful, not arbitrary, and should be consistent with existing practices where possible.

Icons/pictographs should not require excessive comprehension time by the driver. Where icons/pictographs are used, their meaning should be intuitively obvious and/or they should employ familiar symbols which are currently in practice. For example, the "Slippery When Wet" warning sign symbol could be used to alert the driver to a low road friction hazard.

[*See specific 2.5.1.2.3 comments in Appendix A*]
[*See Review and Discussion Issue #7, Comment 3 in Appendix B*]

2.5.2 CHARACTERISTICS OF VISUAL IMMINENT CRASH AVOIDANCE WARNINGS.

An imminent crash avoidance warning should be presented by means of a prominent, rapidly flashing red indicator(s), and should meet all criteria for primary visual displays (Section 2.5.1.1). Imminent crash avoidance warnings should be obviously brighter and more conspicuous than all other proximal displays. No other types of warnings, or other in-vehicle displays, should share this set of features. Use of flashing displays should be avoided for any other application, other than those now standard in vehicles (e.g., turn signals, hazard indicator), and any displays that do flash should have a discriminably slower flash rate than the imminent warning display.

The imminent crash avoidance warning should have the highest attention-getting capability of any display within the vehicle. The intensity required should be appropriate for the type and location of the display used (e.g., HUD, LED on side view mirror, etc.). Because human factors guidelines recommend that red flashing displays be used to indicate emergency conditions due to their superior conspicuity and intrusiveness (MIL-STD-1472D), red flashing displays are reserved exclusively for primary imminent warning displays for all crash avoidance devices. Reserving these unique features for the imminent warning display will likely reduce driver confusion when a warning is presented, thus minimizing time required to perceive, comprehend, and react to the hazardous situation. Flashing displays should be avoided for other in-vehicle applications in order to minimize confusion and promote reliable and rapid driver response to time critical safety warnings.

[*See specific 2.5.2 comments in Appendix A*]

2.5.2.1 Flash Rate.

Imminent crash avoidance warnings should have a flash rate of 5 flashes per second with equal on and off times.

Human factors guidelines generally recommend flash rates from 3 to 5 per second with equal on and off times (MIL-STD-1472D; VanCott and Kinkade, 1972). Because of the limited time available to alert the driver in a crash avoidance situation and the increased sense of urgency, flash rates in the upper end of this range are advisable. Additionally, such high flash rates will be readily distinguished from any other in-vehicle flashing modes such as turn indicators or hazard flashers.

[*See specific 2.5.2.1 comments in Appendix A*]

2.5.2.2 Flash Synchrony.
If two or more imminent crash avoidance warnings occur simultaneously, the flashes should be synchronous.

Simultaneously flashing lights should have synchronized flashes (MIL-STD-1472D), since asynchronous flashing may be confusing and disturbing to the driver. Although this requirement may be easily carried out within a crash avoidance warning device, it poses some difficulties across devices, unless an integrated system is designed.

[*See specific 2.5.2.2 comments in Appendix A*]

2.5.2.3 Visual Display Deactivation.
Imminent crash avoidance warning displays should be capable of being turned off only by turning the entire device off or by deactivating the device (i.e., placing the device in the standby mode). Manual overrides for imminent crash avoidance warnings should be avoided.

Imminent crash avoidance warning displays should function at all times when the device is activated. The driver should not be able to turn off the visual displays while the system is operational since visual warning displays are critical when information must be conveyed concerning multiple simultaneous warnings (see Section 2.3.3).

[*See specific 2.5.2.3 comments in Appendix A*]

2.5.3 CHARACTERISTICS OF VISUAL CAUTIONARY CRASH AVOIDANCE WARNINGS.
The following features should be used to indicate cautionary crash avoidance warnings:

CONTINUOUS RED: for devices with one level of cautionary warning, a continuous red display indicates a cautionary crash avoidance situation; for devices with multiple levels of cautionary warning, a continuous red display indicates the highest level cautionary crash avoidance situation

CONTINUOUS YELLOW/AMBER: if color coding is used to identify multiple levels of cautionary warning, a continuous yellow/amber display indicates the second highest level of cautionary warning

Green indicators should not be used in cautionary crash avoidance warning displays.

[*See specific 2.5.3 comments in Appendix A*]

2.5.3.1 Display by Exception.
If no target or critical situation is sensed by the crash avoidance sensor system, there should be no display to the driver.

Some current warning systems provide a green "safe" or "go" display, or a yellow/amber "caution" display, to indicate conditions where no target or critical situation is being sensed. This type of indication implying safety may discourage the driver from actively monitoring the traffic situation, regardless of any instructions to the driver that warning systems are only a supplement to normal visual monitoring. Because the onset of a signal is more conspicuous than a change in an existing signal, warnings will be more conspicuous when there is no signal in the absence of a warning. In addition, presenting a signal in the absence of any specific crash avoidance situation will contribute to a proliferation of signals within the vehicle, leading to driver overload and confusion.

[*See specific 2.5.3.1 comments in Appendix A*]

2.5.3.2 Size.
Indicator lights should subtend a minimum visual angle of 1 degree. Other modes of display (e.g., CRT, HUD) should provide an equivalent level of conspicuity (TBD).

A visual angle of 1 degree is based on the recommendation of Veitengruber, Boucek, and Smith (1977) for aircraft warning displays. However, system developers are strongly encouraged to determine the appropriate size through testing, because detection of indicators depends on size, luminance, and exposure duration. In addition, the appropriate size will depend on the technology being used (e.g., LED, CRT, HUD).

[*See specific 2.5.3.2 comments in Appendix A*]

2.5.4 CHARACTERISTICS OF STATUS INDICATORS.
The operational status of warning devices should be displayed to the driver by means of status indicators. Each warning device should have its own status indicator which clearly identifies its associated warning device. Status displays should be less conspicuous than and easily discriminable from warning displays. Status displays should not distract the driver's attention from the warning displays.

[*See specific 2.5.4 comments in Appendix A*]

2.5.4.1 Power Indication.
A positive indication of power to the device should be provided. The absence of display

illumination should be used to indicate that the device has been manually turned off by the driver or that the device is not being properly supplied with electrical power.

Typical in-vehicle warning displays (e.g., oil pressure) show status transiently when the vehicle's engine is started, and displays are presented only when failures occur. However, these systems are always "on", that is, the driver cannot turn off or override the function. Warning devices, however, can be manually turned off by the driver. Therefore, the absence of a signal has an ambiguous meaning (e.g., no hazard, system not on), thus necessitating a positive indication of status. This requirement is clearly stated in most human factors standards and guidelines (MIL-STD-1472D, DOE-STD-HFAC, MIL-HDBK-759B).

[*See specific 2.5.4.1 comments in Appendix A*]

2.5.4.2 Color.
The following colors should be used to indicate status information:

GREEN: to indicate that the device is turned on and has passed diagnostic testing
RED or YELLOW/AMBER: to indicate that the device is turned on, but is not functioning properly as determined by built-in diagnostic testing

The driver must be given a positive indication of a operational status of the device. The recommended status indicator colors are based on population stereotypes and general human factors practice which recommends that when color coding is used, green indicates "go", "safe", or "on", red indicates "stop" or "fail", and yellow/amber indicates "caution" (MIL-STD-1472D, DOE-STD-HFAC). Since a continuous red indicator is also being used to code cautionary crash warnings, care should be taken by the designer of the device to ensure that status indicators and warning displays of the same color are readily discriminable from one another. Differentiation may be accomplished by varying size, brightness, shape, functional grouping, and/or location of the displays. If status indicators and warning displays are too similar, driver confusion errors are likely, leading to longer comprehension time and weakened perception of the hazard.

[*See specific 2.5.4.2 comments in Appendix A*]

2.5.4.3 Flashing.
Flashing indicators should not be used to indicate the operational status of warning devices.

Because of their superior conspicuity, flashing visual displays should be reserved strictly for imminent crash avoidance warning displays. Thus, flashing displays should not be used to indicate operational status of the device.

2.5.4.4 Location.
Status indicators should be located separate from warning displays, but should be clearly visible from the driver's position. One central location for all warning device status indicators is preferred. A single segmented status display may be used to indicate the status of multiple devices.

The time required to obtain status information must be minimized if the driver is to maintain an acceptable level of vigilance to detect hazards in the road ahead. For this reason, status indicators should be situated and functionally grouped in a location where they can be easily read in a glance. Status displays should, however, be located separate from warning displays to avoid driver confusion. Functional grouping also assists in reducing the amount of time spent in searching for status information. Scattering status indicators in different locations on the dashboard should be avoided since it increases search time and interrupts normal driver attention to the road.

[*See specific 2.5.4.4 comments in Appendix A*]

2.6 TACTILE DISPLAYS.

This section presents guidelines for tactile warning displays. Tactile displays may be presented in the form of mechanical vibration (i.e., vibrating steering wheel or seat pan) or counterforces on vehicle controls (i.e., upward force on accelerator pedal).

[*See specific 2.6 comments in Appendix A*]

2.6.1 COMPATIBILITY OF WARNING TO DRIVER RESPONSE.

The type of tactile display chosen and the location of the display with reference to the driver's body, should be such that the driver can easily associate the display with a particular crash avoidance situation and determine an appropriate response. The warning should adequately capture the driver's attention without startling the driver.

Tactile displays are most commonly utilized in aircraft. Examples include the stick-shaker (indicates proximity to a stall), foot-thumper (indicates cycling of the anti-skid system), and stick-pusher (assists the pilot in reducing the danger of a stall). However, tactile displays are not currently widely used in automobiles, although there are a couple of examples, such as applying counterforces on the accelerator and brake pedals. SAE ARP 450 (1971) requires that the use of tactile displays be minimized. In addition, Veitengruber *et al.* (1977) and Berson *et al.* (1981) note that tactile warnings are not recommended in the commercial transport environment because they are disruptive, although it is not known to what degree these displays are "disruptive".
The driver should be able to form a natural association between the tactile display and the crash avoidance situation it represents and, possibly, the appropriate

action to be taken in response to that situation. For example, accelerator pedal pressure may provide an appropriate crash avoidance display for headway warning situations where the driver must slow down or brake (Nilsson, Alm, and Janssen, 1991). It would probably be less effective as a display in the case of a blind spot device or a drowsy driver alerting device. Among the possible tactile display locations in an automobile are the steering wheel, the accelerator pedal, and the driver's seat (i.e., bottom and back).

[*See specific 2.6.1 comments in Appendix A*]

2.6.2 VIBROTACTILE DISPLAYS.
The following guidelines address display parameters for vibrotactile displays.

2.6.2.1 Frequency.
Vibrational frequencies of 100 to 300 Hz should be used. Vibrational frequencies of 3 Hz should be avoided.

Humans are most sensitive to vibration in the 100 to 300 Hz range (Verillo, 1966). Frequencies within this range are also unlikely to be masked by road-induced vibration of the vehicle, which generally occurs at a lower frequency. A vibrational frequency of 3 Hz is the resonating frequency for the internal organs of the human body. A vibrotactile display which matches this frequency may cause nausea and discomfort and, thus, should be avoided.

[*See specific 2.6.2.1 comments in Appendix A*]

2.6.2.2 Intensity.
Display intensity should be 20 to 30 dB above masked vibratory threshold, as measured in the vehicle under all anticipated normal driving conditions.

Gilson (1992) recommends a display intensity value of 20 to 30 dB above masked vibratory threshold. The intensity of the display should be sufficient to alert the driver without creating a startle effect or interfering with performance of the driving task. Consideration should be given to roadway vibration, vehicle vibration (e.g., luxury car vs. commercial truck), clothing worn by the driver (e.g., heavy gloves, boots, etc.), and vehicle seat covers (e.g., sheepskin, wooden beads, etc.).

2.6.2.3 Duration.
Vibrotactile displays, once activated, should cycle continuously until the crash avoidance situation no longer exists, the driver has taken appropriate corrective action, or the display has been manually terminated.

[*See specific 2.6.2.3 comments in Appendix A*]

2.6.2.4 Pulse Rate.
The on-off cycle for pulsed vibrotactile displays is TBD.

Vibrotactile displays may be of two types, continuous or pulsed. The on-off cycle for pulsed displays must be determined through testing, since insufficient data exist to recommend a value in these Guidelines. Pulse rates will likely be application-specific, depending on the location of the display.

2.7 CONTROLS/ADJUSTMENTS.
The following guidelines apply to controls associated with visual, auditory, and tactile displays for in-vehicle crash avoidance warning displays.

2.7.1 MASTER INTENSITY CONTROL.
A single master control may be provided to permit the driver to simultaneously adjust the intensity of all displays of a specific mode (e.g., auditory, visual, tactile) for a specific device or for an integrated system. Intensity adjustment should be restricted such that at the lowest setting the display remains perceptible for all anticipated driving conditions and at the highest setting does not startle the driver.

Since the in-vehicle environment (e.g., ambient noise, lighting, vibration) will vary depending on specific driving conditions, and in order to accommodate individual perceptual capabilities and preferences, the driver should be given the opportunity, to adjust the intensity of the warning indicators. However, it is imperative that adjustability be restricted in order to prevent reducing intensity to an imperceptible level under the anticipated range of driving conditions, and to prevent increasing the intensity to a level which startles the driver.

[*See specific 2.7.1 comments in Appendix A*]
[*See Review and Discussion Issue #10 in Appendix B*]

2.7.2 PHYSICAL CHARACTERISTICS OF CONTROLS.
Controls should be designed to facilitate the driver's identification and selection of the correct control for the intended function. Controls should be readily recognizable. Possible confusion among controls should be minimized. These objectives should be achieved through both labeling and the appropriate coding of controls along several physical dimensions, including shape, size, texture, and color. If touch panels are used, they should be used only for discrete, not continuous, control functions. Refer to MIL-STD-1472D, Section 5.4, for additional design requirements.

2.7.2.1 Labeling.
The function of all controls should be identified in a manner which is salient, legible, and visible to the driver before the driver reaches for the control. Labels should be placed in such

a way that the driver's hand will not cover the label when reaching for the control. Labels may be either be alphanumeric or iconic/pictographic in nature. Labels should generally be oriented horizontally. If used, vertical labels should read from top to bottom.

Labeling is the "minimum coding requirement for any control" (Sanders and McCormick, 1993). However, labels will not be effective if the driver cannot see them. Labels must be oriented for ease and speed of reading/recognition (MIL-STD-1472D). For detailed recommendations on labeling, see MIL STD-1472D, Section 5.5, Labeling.

[*See General Comments in Appendix C*]

2.7.2.2 Shape.

Controls for different functions should be shaped differently to reduce confusion and head-down time.

When controls are all the same shape, they are easily confused and require more head-down time for identification and selection. Shape coding is more effective than size coding (Sanders and McCormick, 1993), and aids the driver in identifying control settings (MIL-STD-1472D). Additionally, non-confusable knob sets reduce errors and head-down time (Sanders and McCormick, 1993).

2.7.2.3 Size.

Size coding of controls should be limited to three discriminable sizes. The following guidelines should be met or exceeded for controls to be discriminable by size: diameters should differ by at least 12.7 to 13 mm, and thicknesses should differ by at least 9.5 to 10 mm.

For size coding to be effective, controls must be sufficiently different in size to make them discriminable from each other (Sanders and McCormick,1993). MIL-STD-1472D as well as Sanders and McCormick (1993) differ slightly in their recommended minimum differences.

[*See specific 2.7.2.3.4 comments in Appendix A*]

2.7.2.4 Texture.

If texture coding is used, controls should be smooth, fluted, knurled, and/or serrated.

Smooth, fluted, and knurled controls can be discriminated reasonably well from each other (Sanders and McCormick, 1993). MIL-STD-1472D requires knobs to be serrated. Precise adjustment knobs are to be finely serrated, and gross adjustment knobs are to be coarsely serrated.

[*See specific 2.7.2.4 comments in Appendix A*]

2.8 USER DOCUMENTATION.

User documentation should assist the installer and driver in effectively trouble-shooting common functional problems of the device. Documentation design should meet the following criteria:

a) Be readable, understandable, and usable by a representative driving population (e.g., eighth-grade reading level),

b) Be highly pictorial, with adequate labeling to identify system parts referred to in the text,

c) Convey a clear conceptual organization to the driver should include the use of titles and headings and the use of a hierarchical numbering system.

d) Convey information about the purpose and functions of each crash avoidance warning device, including the nature of the warnings and failure indicators,

e) Provide instructional or procedural material in a list, such as a series of steps to take responding to a particular failure indicator,

f) Be easily integrated with existing driver's manuals.

User documentation is not likely to be read by the driver unless a problem arises with the device. Since expected users of warning systems represent a cross-section of the general population, user documentation should be readable and understandable by representative drivers. Text should be written for an eighth-grade reading level. This is the standard reading level for newspapers that are aimed at a mass audience. Readability is based on word difficulty and sentence complexity. The preferred average sentence length is 17 words or less. Both readability and usability should be tested and validated.

Documentation should be attractive and easily integrated with existing driver's manuals (FAA-D-2494/b; MIL-M-GCSFUI; Angiolillo and Roberts, 1991; Simpson and Casey, 1988). The visual structure should assist drivers in finding the required information. The visual hierarchy should distinguish major concepts from subconcepts and one category of information from another (Wright, 1983). Text should be both descriptive and procedural. Descriptive material should be provided in paragraph form and convey information about the purpose and functions of each crash avoidance warning device, including the nature of warning and failure indicators (Simpson and Casey, 1988; Gribbons, 1992). Material must be organized so that drivers can quickly find what they are looking for. These concepts are outlined in FAA-D-2494/b, MIL-STD-962B, and MIL-STD-490A.

[*See specific 2.8 comments in Appendix A*]

3.0 BLIND SPOT WARNING DEVICES.

The following guidelines should be used in conjunction with the general guidelines in Section 2.0.

3.1 DEVICE APPLICATION.

This section addresses blind spot detection devices which are intended to alert the driver travelling on a roadway to the presence of all potentially conflicting vehicles located in areas of poor visibility lateral to the vehicle. This application is distinguished from other warning applications for maneuvers such as backing or parking.

Blind spot detection systems are designed to address lane change/merge crashes, where one vehicle encroaches into the lane of another vehicle. The basic intent is to alert the driver of the conflicting vehicle. A signal may be presented simply by virtue of two vehicles being in close proximity, or a more complex algorithm based on such factors as driver action (e.g., turn signal activation, lane deviation) or time-to-target measurements may be used to warn a driver that he or she is approaching another vehicle. Current products are often designed and marketed for large commercial vehicles, in particular, because of more severe visibility problems.

The crash situations addressed by these devices are those in which two vehicles are traveling in the same direction on a roadway, and some possible maneuver, such as a lane change or merge, can bring those vehicles into conflict. There may be other situations where the proximity to a target object is sensed, as in aids to backing or parking, or in warning about pedestrians adjacent to a vehicle such as a bus. Even if similar sensor systems are used, it is important to distinguish among these situations.

[*See specific 3.1 comments in Appendix A*]
[*See General Comments in Appendix C*]

3.2 DEVICE ACTIVATION.

The system should be automatically activated whenever the ignition switch is turned on and the vehicle is placed in forward gear. It is permissible to preclude warning signals if the vehicle is travelling below some low criterion speed.

By requiring the vehicle to be in forward gear, some nuisance alarms for lane change blind spot devices can be eliminated. Deactivating the device at a very low speed of travel (i.e., 5 miles per hour) provides another potential means for further eliminating inappropriate warnings. Inappropriate warnings may occur when turning corners, parking the vehicle, and in other situations where through driving is not possible.

[*See specific 3.2 comments in Appendix A*]

3.3 PRIMARY VISUAL DISPLAY LOCATION.

The primary visual display for all levels of warning should be located at or within 15 degrees vertically above the line of sight of the side view mirror on the same side of the vehicle as the related detector system. The visual indicator must be located at, or within 15 degrees horizontally forward of, the line of sight of the side view mirror. Additional visual displays may supplement, but not replace, this primary visual indicator.

Visual signals are more detectable when located close to the line of sight. Most human factors guidelines indicate that important visual information should be located within 30 degrees of the normal line of sight, with the most critical information being located within 15 degrees of the line of sight (MIL-STD-1472D; Boff and Lincoln, 1988). A variety of glance locations may be associated with lane changing, and pending research, the optimal visual display location will be determined. The recommendation here is based on the idea that, prior to or at the initiation of a lane change maneuver, the driver will likely look toward the lane he or she is moving into and/or at the side view mirror. In either case, a signal located at or forward of the side view mirror is likely to be in the effective field of visual detection. In contrast, interior rear view mirror locations may only be effective if the driver uses that mirror at the time of the lane change. Immediately forward locations will not be as effective if the driver is monitoring the side mirror or adjacent lane. It may prove that locations other than the primary one specified here are important, and perhaps multiple locations will be required. Pending such research, however, other locations should be treated as optional supplements to the primary side-mirror location. Side mirror locations also inherently provide unambiguous directional cues. Furthermore, other locations may draw driver attention away from the direction of the hazard, whereas the recommended location is consistent with monitoring the hazard.

[*See specific 3.3 comments in Appendix A*]
[*See Review and Discussion Issue #3, Comment 10 in Appendix B*]

3.4 LEVELS OF WARNING.

The system should provide at least two levels of warning, an imminent crash avoidance warning and a cautionary crash avoidance warning.

The apparent impulsivity of lane changes resulting in collisions indicates the need for some pre-maneuver information (e.g., cautionary warning) about the presence of vehicles in the blind spot, even if these cannot be considered imminent crash situations prior to some indication of a change of path. Additionally, some current products distinguish two levels of proximity between vehicles. The usefulness of this additional information for actual driver behavior is not known.

[*See specific 3.4 comments in Appendix A*]

3.4.1 IMMINENT CRASH AVOIDANCE WARNINGS.
Imminent crash avoidance warnings should be provided to alert the driver to an imminent crash avoidance situation. Imminent crash avoidance warnings for blind spot devices should comply with Sections 2.4.1 and 2.5.2.

DEFINITION OF IMMINENT CRASH AVOIDANCE SITUATION: An imminent crash avoidance situation exists when a target object is sensed in the detection zone (i.e., blind spot) and there is an indication of the vehicle's change of path that brings it into potential collision with that target. A signal of driver intent to change path, specifically activation of a turn signal in the direction of the potentially conflicting target vehicle, is sufficient to define an imminent crash avoidance situation. Additional measures may be used to define an imminent crash avoidance situation including: 1) directly sensing a change in vehicle path (i.e., lane deviations, lateral acceleration, steering actions, etc.); and/or 2) detecting extremely close vehicle proximity to the target object or vehicle. This distance-to-target measurement should extend from the side of the vehicle at least 18 inches (upper limit TBD).

Vehicles frequently may be in a driver's blind spot without providing the threat of an imminent collision. Such a threat only occurs when the vehicles' paths converge. Therefore, to prevent numerous inappropriate alarms, the imminent crash avoidance warning should only be provided when there is an indication of a change of lane or other convergence. When an object is detected in the blind spot and turn signals are activated, such signalling should be sufficient to define the imminent crash situation, since it is an unambiguous indicator of a driver's intent to change course. This definition will also normally provide adequate warning time, given that the driver uses the turn indicator. A review of driver lane changing studies (Finnegan and Green, 1990) suggests that the visual search and decision time preceding the initiation of an actual lane change is on the order of several seconds (although the point during this interval at which a turn signal would typically be actuated is not described; furthermore, the research reviewed used experienced drivers as research subjects, and not actual traffic behavior).

However, there are two important limitations of this criterion: (1) the possibility of inappropriate imminent crash avoidance warnings for anticipatory signalling (addressed in a following section); and (2) it only addresses cases where the driver signals his or her intent to change lanes. This latter limitation is of particular concern, given the probable abrupt nature of lane changes suggested by police reports. For this reason, additional defining conditions for the imminent crash situation may be useful to supplement the turn signal criteria. These alternatives include directly sensing movement toward another vehicle, movement out of a lane, or a vehicle control action such as steering. Another possibility is to sense very near proximity, which would cover situations where either vehicle encroaches and cases where there is a gradual drift toward another vehicle. There will obviously be a trade-off in the definition of being "extremely close" between warning time and false alarms. Data sufficient for defining a reasonable criterion point were not found. The minimum of eighteen inches is based on the assumption that the delineated lane line itself should provide up to six inches of separation. The *Manual on Uniform Traffic Control Devices,* Section 3A, states that a "normal width line is 4" to 6" wide" (MUTCD, 1988), so at least one of the two vehicles must be as close as six inches to the lane line. Optimal defining criteria for any of the factors described here would be aided by better information from actual traffic regarding the speed of lane changes by non-signalling vehicles and the distribution of lateral separation between vehicles on various types of roads.

FEATURES: The imminent crash avoidance warning should provide a visual display along with an auditory or tactile display (see Sections 2.4.1, 2.4.6, 2.5.3, and 2.6).

[*See specific 3.4.1 comments in Appendix A*]

3.4.2 CAUTIONARY CRASH AVOIDANCE WARNINGS.

Cautionary crash avoidance warnings should be provided to alert the driver to a cautionary crash avoidance situation which does not meet the criteria of an imminent crash avoidance warning situation.

DEFINITION OF CAUTIONARY CRASH AVOIDANCE SITUATION: A cautionary crash avoidance situation is one in which there is an object in the detection zone (blind spot), but the object is not within the immediate or intended pathway of the vehicle.

FEATURES: The cautionary crash avoidance warning should provide a visual warning display to the driver (Section 2.5.3). Auditory or tactile warnings should not be used for cautionary warnings for the blind spot application.

Because vehicles located in the blind spot area are a normal, frequent occurrence during driving, cautionary crash avoidance warnings will be presented quite often to the driver. Auditory and tactile warnings are too intrusive to be used with such frequency. The annoyance factors associated with cautionary warnings would likely lead to the driver turning off the system. However, because the driver should have some type of feedback from the system concerning surrounding traffic, a visual display should be provided whenever there is a target object in the blind spot sensor field. A visual display is not likely to be as annoying as an auditory or tactile warning and, thus, would probably be more readily accepted by the driver.

[*See specific 3.4.2 comments in Appendix A*]

3.5 DETECTION ZONE CHARACTERISTICS.

[*See specific 3.5 comments in Appendix A*]

3.5.1 AREA OF COVERAGE.

The sensor system should cover the entire blind spot area. The detector field should reliably capture small potential target vehicles (e.g., motorcycles) in all likely lane positions. The detector field should not extend more than 10 feet laterally from the side of the vehicle.

For large commercial vehicles such as tractor-trailer rigs, the blind spot is spatially extended. If the sensed area does not fully correspond to the "blind spot" region for a particular vehicle, there is a risk that driver reliance on the warning device may result in false assumptions of safety. Similarly, "spot" coverage of the detection zone could result in undetected vehicles in the region between sensor fields. This is obviously more of a concern for large commercial vehicles where multiple sensors are required to cover the blind spot area.

Lateral constraints on the detection zone are recommended to preclude activation of the warning by other vehicles separated by an intervening lane. The limitation of a maximum lateral field of 10 feet is a preliminary recommendation. Although 12 feet is the predominant lane width on most types of highways and the generally accepted lane width on main highways (AASHTO, 1990), 10-foot lanes are often used on low-speed roadways. A 10-foot extension of the detection zone will provide sufficient coverage for a 12-foot lane, but any extension beyond 10 feet will often be detecting targets that are not potential hazards (e.g., more than one lane away) and will result in a proliferation of nuisance warnings. The sensor field need not necessarily extend to this maximum, but should be sufficient to capture motorcyclists located toward the side of their lane furthest from the sensors. In fact, these smaller, less conspicuous vehicles may be those that benefit most from such detection devices.

Blind spot warning devices may be susceptible to high nuisance warning rates on roadways with three or more lanes. Consider the scenario where the subject vehicle is making a safe lane change, with no vehicles in the blind spot, but there is a vehicle two lanes over which will eventually be in the subject vehicle's blind spot when the lane change occurs. After the lane change maneuver has begun (e.g., half-way, one-quarter of the way, or less into the maneuver), the driver of the subject vehicle would receive a subsequent warning that a vehicle is indeed in the blind spot, even though the vehicle poses no threat of collision during the intended maneuver. In such a case, the 10-foot recommendation for lateral extension of the detector field may need to be driven even lower, possibly down to 8 or even 6 feet. It is not known how far into the maneuver a driver needs to be when the subsequent warning is given before he or she feels that the maneuver should be aborted. The possibility of operator manual control of the field width is discussed in Section 3.8.1.

[*See specific 3.5.1 comments in Appendix A*]
[*See General Comments in Appendix C*]

3.5.2 LOCATION OF DETECTION ZONE.

[*See specific 3.5.2 comments in Appendix A*]

3.5.2.1 Light/Passenger Vehicles.

Monitoring blind spots on both sides of the vehicle is preferred.

[*See specific 3.5.2.1 comments in Appendix A*]

3.5.2.2 Heavy/Commercial Vehicles.

Sensors may monitor the blind spot only on one side of the vehicle. Monitoring both sides is preferred. If only one side of the vehicle is equipped, sensors should be positioned to cover the right side blind spot area.

Visibility problems around light/passenger vehicles are fairly symmetrical, as reflected in accident data. In a recent analysis of the 1991 General Estimates System (GES) and Fatal Accident Reporting System (FARS), Wang and Knipling (1993) found that the likelihood of a lane change/merge accident occurring on the left side of the vehicle (42.5%) was only slightly greater than one occurring on the right side (38.9%). Although devices that only provide warnings for one side of light/passenger vehicles may still be of some benefit, dual side monitoring is recommended. In the same study, combination-unit truck accidents were also studied. The vast majority of lane change/merge crashes occurred on the right side of the vehicle (63.1%), while only 18.5% occurred on the left side. Thus, large commercial vehicles have a particular need to warn about hazards to the right side of the vehicle. Since it is not known whether experience with blind spot warning devices might result in decreased direct visual monitoring by the driver, there may be risks from altering driver behavior without corresponding benefits from the additional side's detection system.

[*See specific 3.5.2.2 comments in Appendix A]*

3.6 INDICATION OF DIRECTION OF HAZARD.

3.6.1 VISUAL WARNING DISPLAYS.

The device should provide a visual indication of the general direction of the hazard for all warnings. Compliance with requirements for primary visual display location (Section 3.3)

will meet this directional requirement.

There are various reasons for requiring that the general direction of the hazard be displayed, and that it be done so visually. It provides a means for rapidly guiding visual search and indicating an appropriate driving response. It promotes the discriminability of the blind spot warnings from other potential warning displays, without imposing cognitive demands associated with more arbitrary coding conventions. Because an indication of a vehicle in the blind spot may occur very frequently, visual information alone is preferable for the cautionary crash avoidance situation, in order to minimize annoyance and intrusion from auditory or tactile sources. Given that the driver becomes familiar with a visual directional signal for the cautionary warning situation, this well-established stimulus-response relationship should also be carried over to the higher-emergency imminent crash situation. Finally, when multiple imminent crash avoidance hazards exist at the same time, directional visual information is required, as discussed in Section 2.3.3 of these Guidelines. Taken together, these considerations require that a visual indication of the general direction of the hazard be provided.

3.6.1.1 In Light/Passenger Vehicles.

The visual display should indicate whether the hazard is to the left or right side of the vehicle. More detailed spatial information is discouraged.

[*See specific 3.6.1.1 comments in Appendix A*]

3.6.1.2 In Heavy/Commercial Vehicles.

The visual display should indicate whether the hazard is to the left or right side of the vehicle. Additional information regarding hazard location is permissible.

For large vehicles, where the blind spot is spatially extended and the visibility problems are more severe, there may be advantages to defining more precise hazard zones around the vehicle, rather than simply indicating to which side the hazard lies. This feature is available in some current devices, although its advantages are unproven. For passenger vehicles, the blind spot area is small and more readily monitored, so that complicating the display and proliferating the number of signals is unwarranted.

[*See specific 3.6.1.2 comments in Appendix A*]

3.6.2 AUDITORY WARNING DISPLAYS.

Auditory warning displays (i.e., spatially-localized acoustic signals, voice messages) may be used to indicate the direction of the hazard. Auditory directional indicators should only be provided for imminent crash avoidance situations and should not be used for cautionary

crash avoidance warning situations.

[*See specific 3.6.2 comments in Appendix A*]

3.6.3 TACTILE WARNING DISPLAYS.

Tactile warning displays may be used to indicate the direction of the hazard. Tactile directional indicators should only be provided for imminent crash avoidance situations and should not be used for cautionary crash avoidance warning situations.

Driver response to directional tactile signals has received little attention. Some human factors design references (Boff and Lincoln, 1988) discourage the use of tactile signals as disruptive or difficult to control. Ongoing research under the European Community DRIVE project has included tactile signals but has reported little information on the driver's immediate reaction to the signals and has provided some suggestion of poorer user acceptance of such tactile warning signals (Janssen and Nilsson, 1990). Pending some demonstration of added benefits of directional warning modalities other than visual and auditory, driver response to specific tactile cues should be thoroughly tested prior to their implementation in warning devices.

[*See specific 3.6.3 comments in Appendix A*]

3.7 TERMINATION OF WARNINGS.

3.7.1 AUTOMATIC TERMINATION OF WARNINGS.

3.7.1.1 Imminent Crash Avoidance Warning Displays.

Imminent crash avoidance warning displays should be automatically terminated only when: 1) the location of the target object no longer meets the defining criteria for an imminent crash avoidance situation; or 2) the system senses a corrective maneuver that appropriately responds to the potential collision.

The imminent crash avoidance warning is intended to induce the driver to respond immediately, and so should remain in effect until that response is made or is no longer required. Normally, this will be indicated by the cessation of the defining conditions for the imminent crash warning situation. However, there may be direct indicators of the vehicle maneuver, even if defining conditions remain. For example, if activating the turn indicator while a vehicle is in the blind spot initiates a warning, the driver may abort a lane change and steer away from the conflicting vehicle. Such a maneuver conceivably could be sensed through measurement of vehicle proximity, lane position, or steering wheel position, even if the turn indicator remains on. In such a case, the initiation of the maneuver would none the less indicate driver response to the warning, and termination of the imminent crash warning would eliminate an unnecessary signal.

3.7.1.2 Cautionary Crash Avoidance Warning Displays.

Cautionary crash avoidance warning visual display should remain on at all times when a target object is detected within the warning zone. The warning should be automatically terminated when the target object moves out of the warning detection zone. Refer to Section 3.7.2 for manual override guidelines.

For the blind spot warning device, the only time that the cautionary visual warning should be automatically terminated is when there is no longer an object detected in the cautionary warning detection zone. The visual display should remain on whenever an object is detected in the blind spot. This will provide the driver with information concerning objects proximal to the vehicle prior to initiating the lane change/merge maneuver.

3.7.2 TRANSIENT MANUAL OVERRIDE OF WARNINGS.

3.7.2.1 Visual Warning Displays.

Transient manual override controls should not be provided for visual warning displays.

Because of the possibility of an unexpected or unnoticed object being in the blind spot of the vehicle (e.g., a motorcycle), a manual override should not completely disarm the device. Visual displays should continue to function, even when auditory or tactile displays are disarmed, so that the driver will continue to have feedback from the device concerning objects in the blind spot of the vehicle.

3.7.2.2 Auditory and Tactile Warning Displays.

Transient manual override controls for auditory and tactile warnings should be provided to allow the driver to override a potential imminent crash avoidance warning when the driver knowingly activates a turn indicator when an object is in the blind spot (i.e., prior to turning a corner, when signalling a lane change in advance). Some positive driver action should be required to activate the manual override control. Requirements for activating the manual override must be compatible with the normal driving task.

If an imminent crash warning is presented whenever a target is sensed and the vehicle is moving laterally, or when a target is sensed and the turn signal is activated, there will be a high potential for false alarms whenever the driver is turning a corner. In such instances, off-roadway hardware, parked vehicles, pedestrians, traffic travelling in the opposing direction, and so forth may be recognized as potential collision hazards in the blind spot, resulting in an imminent warning being presented to the driver. Nuisance alarms may also result from the driver signalling his or her intent to change lanes prior to the time when a safe gap is actually available. Nuisance alarms may contribute to poor user product acceptance, degrade driver response to valid warnings, and discourage drivers from using turn signals when they should.

To prevent nuisance alarm problems, some means is required for discriminating turns and advanced signalling from lane changes or other maneuvers that could result in blind spot collisions. Since no current products offer a technology for directly sensing turn maneuvers and advanced signalling from lane change maneuvers, a driver action appears to be the most likely method. The requirement for a positive driver action to indicate a lane change is to ensure that the sensor system will provide a warning *unless* the driver takes an action that will cause it to be overridden. For example, a button or switch could be placed on the turn signal stalk, or a second more extreme position for the stalk could be provided, in order to allow the driver to intentionally override the auditory or tactile warning under these typical conditions which initiate inappropriate alarms. However, the design of the manual override control must be compatible with normal driving.

[*See specific 3.7.2.2 comments in Appendix A*]
[*See Review and Discussion Issue #3, Comment 10 in Appendix B*]

3.8 DETECTOR SENSITIVITY ADJUSTMENT.
A control may be provided to allow the driver to adjust the range of the sensor field to reduce sensitivity and false alarm rates. Controls/adjustments should meet all requirements for controls/adjustments in Section 2.7.

There may be unanticipated or uncontrollable operational situations in which the warning device falsely perceives frequent "hazards." For example, sensors mounted on a wide vehicle (e.g., commercial truck, bus) and/or narrow lanes may cause triggering by objects across the adjacent lane (e.g., concrete safety barriers) or even by vehicles two lanes away. Sensitivity adjustments would be useful for such situations.

[*See specific 3.8 comments in Appendix A*]

4.0 BACKUP WARNING DEVICES.

The following guidelines should be used in conjunction with the general guidelines in Section 2.0.

[*See specific 4.0 comments in Appendix A*]

4.1 DEVICE APPLICATION.

This section addresses backup warning devices which are intended to provide warnings for backing "encroachment" crashes, but are not applicable to "crossing path" crashes. Backup warning devices are to be used specifically as safety warning devices and are distinguished from devices which are designed to function strictly as parking aids.

Backing crashes can be separated into "encroachment" crashes and "crossing path" crashes (Knipling, 1993; Tijerina, *et al.*, 1993; Wang and Knipling, 1993). Encroachment backing crashes are characterized by slow closing speeds and a backing vehicle which strikes a stationary or slowly moving object (e.g., pedestrian, post, vehicle). This type of crash accounts for approximately 43 percent of all backing crashes. Crossing path crashes, on the other hand, generally involve higher closing rates, where the backing vehicle collides with another vehicle which is typically moving at speed on a roadway (i.e., vehicle backing out of a driveway). Crossing path crashes account for approximately 57 percent of all backing crashes.

Because of the slow closing rates involved in encroachment backing crashes, backup warning devices provide a useful safety countermeasure for avoiding such crashes. However, because of the higher closing rates involved in crossing path crashes, more intelligent sensor systems than are currently available would be required to alert the driver to the presence of conflicting vehicles. For this reason, these Guidelines address only those devices which warn the driver of encroachment crash situations.

Although many backup warning devices are currently set forth as safety products, most are actually designed to function as parking aids and are not necessarily adequate for use as safety warning devices. Parking aids do not necessarily have to capture the driver's attention; rather, they are available for the driver to monitor, should he or she choose to use them. While parking aids are intended to provide supplemental information to the driver relative to predictable situations (e.g., distance to loading dock), safety warning devices are intended to alert the driver to *unexpected* and *unforeseen* objects within the pathway of the vehicle. Therefore, unlike parking aids, safety warning systems must provide an attention-getting warning to the driver when potential collision hazards are sensed within the detection zone.

Parking aids must be distinguished from backup warning devices because products that function effectively as parking aids may perform poorly as warning devices. The user of a backing device should be provided a clear understanding of the system's function, and devices that do not adequately provide warning alerts should not be set forth as warning devices. These Guidelines specifically address the crash avoidance warning functions of backing devices and do not apply to devices intended to function solely as parking aids.

[*See specific 4.1 comments in Appendix A*]

4.2 DEVICE ACTIVATION.

The device should be automatically activated whenever the ignition switch is on and the vehicle is placed in reverse gear. The device may also be activated whenever the engine is on and any motion in the reverse direction is detected, even if the vehicle is not in gear.

4.3 PRIMARY VISUAL DISPLAY LOCATION.

[*See specific 4.3 comments in Appendix A*]

4.3.1 IN LIGHT/PASSENGER VEHICLES.

For vehicles where direct viewing of the rear area of the vehicle is possible (i.e., passenger cars, pick-up trucks), primary visual displays should be located near the rear window within 15 degrees vertically and within 15 degrees horizontally of the driver's line of sight while looking out the back window while backing. The visual display near the rear window should be positioned so that it is clearly visible in the rear view mirror. It is permissible to allow the driver to locate the primary display at a preferred location, within 15 degrees of the line of sight of the side view mirrors, rear view mirror, and/or rear window. Primary displays should not be located on the vehicle dashboard.

Primary visual displays should be located in positions which encourage drivers to either look directly toward the rear of the vehicle or to use their mirrors during the backing maneuver. Drivers of smaller passenger vehicles can usually look directly out of the rear window while backing. By locating the primary visual display on the rear window in the driver's line of sight, this behavior will, most likely, be reinforced rather than discouraged. The primary display on the rear window should also be clearly visible in the rear view mirror to provide added redundancy for the driver. Visual displays may be placed on or near the side view mirrors or rear view mirror of passenger vehicles to provide additional information to the driver. However, these locations do not encourage direct viewing of the rear of the vehicle and may not provide an ideal location for primary displays. Because there is currently no consensus on driver looking behavior while backing, and because of the likely diverse personal preferences in primary display location, the driver is given the option to locate the primary display on the side view mirrors, rear view mirror, and/or back window.

[*See Review and Discussion Issue #3, Comment 10 in Appendix B*]

4.3.2 IN HEAVY/COMMERCIAL VEHICLES.

For vehicles where direct viewing of the rear area of the vehicle is not possible (i.e., large commercial trucks, school buses), it is recommended that primary visual displays be located on each of the side view mirrors within 15 degrees vertically and within 15 degrees horizontally of the driver's line of sight of the mirrors. Primary displays should not be located on the vehicle dashboard.

Because drivers of large commercial vehicles depend heavily on their side view mirrors for backing, primary visual displays should be located in positions which encourage drivers to use their mirrors. The primary display should be located in the line of sight of the mirrors so that the driver does not have to take his eyes off of the mirror to verify the presence of objects in the detection zone.

4.4 LEVELS OF WARNING.

The device should provide multiple levels of cautionary warnings. Devices which provide continuous analog-type warnings relative to changes in distance- or time-to-target meet this multi-level criteria. An additional imminent crash avoidance warning is desirable. This is an exception to Section 2.2.

At least two levels of cautionary warning should be provided to the driver rather than providing only a general indication of the presence of an object in the detection zone. This is an exception to the general recommendation for a single cautionary warning level on crash avoidance warning devices. Because drivers often need additional information beyond discrete levels of warning when backing, there must be some way for the driver to discriminate different levels of proximity of the target object. Devices which provide continuous analog-type displays which increase in acoustic pitch, beep rate, flash rate, etc. as the rear of the vehicle approaches the target object meet this multi-level warning requirement. Consider the following scenario for a device with only one level of warning: A driver receives a general alert indicating the presence of an object within the rear detection zone of his vehicle. After scanning the area to the rear of his vehicle, he interprets the signal to be related to an obvious vehicle parked 8 feet behind him. This signal, however, is actually alerting the driver to the presence of a child sitting on the ground 2 feet from the rear of his vehicle. Because the driver has no information to contradict his interpretation of the situation, he begins backing and seriously injures or kills the child. In this case, a second higher level of warning would have provided the necessary information to the driver to avoid the crash.

Although backup warning devices should ideally present an imminent crash avoidance warning to the driver, current devices may not be able to accurately detect an imminent crash avoidance situation in accordance with Section 4.4.1 for backing maneuvers. Because of the nature of backing maneuvers, vehicles often are intentionally in close proximity to obstacles. Thus, more intelligent systems are required to detect those situations that are actually imminent crash situations.

[*See specific 4.4 comments in Appendix A*]
[*See General Comments in Appendix C*]

4.4.1 IMMINENT CRASH AVOIDANCE WARNINGS.
Imminent crash avoidance warnings may be provided to alert the driver to an imminent crash avoidance situation. Imminent crash avoidance warnings for backup warning devices should comply with Sections 2.4.1 and 2.5.2.

DEFINITION OF IMMINENT CRASH AVOIDANCE SITUATION: The imminent crash avoidance situation exists when: 1) the backing vehicle is in very close proximity to the target object (TBD); 2) time-to-target is less than the 95th percentile hard braking stopping time for backing maneuvers (TBD); or 3) an abrupt change in distance- or time-to-target is detected. The imminent crash avoidance warning should be readily discriminable from other backing warnings and from all other warnings inside and outside the vehicle.

Imminent crash avoidance warnings should be reserved for those critical, and most likely unintentional, situations which require immediate braking. Because of the implied criticality of the warning, it should be readily discriminable from both the imminent and cautionary warnings.

Because of the variety of backing maneuvers performed, devices which simply measure distance-to-target do not lend themselves well to imminent crash avoidance warning situations since the backing driver will often intentionally bring the vehicle close to fixed objects. The specified distance must be so close to the rear of the vehicle that it is unlikely to be an intentional encroachment; yet, the distance cannot be so large as to produce a proliferation of nuisance alarms for maneuvers such as parallel parking. Although the data do not currently exist, this distance may be determined by observing vehicle parking maneuvers to determine the proximity zone within which most vehicles do not enter when parking.

For those systems which are capable of measuring time-to-collision, an imminent crash avoidance warning situation would occur when the time-to-collision is less than the 95th percentile stopping time for backing maneuvers. The stopping time is the sum of the driver braking time for backing maneuvers and the vehicle reaction time. Driver braking reaction times must be known in order to determine the recommended imminent crash avoidance zone of coverage for the sensor. Although no data are available which indicate brake reaction times for the backing maneuver, reaction times for unalerted forward driving subjects have been studied. Although a variety of studies have reported data on brake reaction time for forward driving situations, these values should not be directly translated to backing maneuver behavior. Reaction times may be somewhat less than those cited for forward driving maneuvers because the driver is more likely to have his or her foot on or near the brake pedal, rather than on the accelerator, while backing. Also, the short maneuver time and the often heightened alertness of the driver during backing maneuvers may affect brake reaction times. Because of these factors, further research must be conducted in order to determine actual driver reaction times. It should also be noted that increasing the time-to-collision requirements to account for higher speeds will probably lead to a proliferation of nuisance alarms. Given the lack of data on backing maneuvers, it is not known how well various time-to-collision measures will be able to discriminate intentional backing maneuvers near recognized objects from unintentional encroachment on unseen or misperceived objects.

An imminent crash avoidance warning situation would also arise when there is a sudden change in time- or distance-to-target. This would indicate that an object had moved into the detection field at a distance closer to the rear of the vehicle than the previously detected object. For instance, if the detectors were sensing a fixed object to the rear of the vehicle and a child ran between the vehicle and the object, an imminent crash avoidance warning should sound to alert the driver to the presence of the child. The warning should be given regardless of how far from the rear of the vehicle the child is. The critical change in distance- or time-to-target measurement necessary to define an imminent crash avoidance situation should be small enough that it can alert the driver to a child, pedalcyclist, etc. that has entered the backing pathway of the vehicle in closer proximity to the vehicle than the previously detected object, even if the person is near the detected object (on the side toward the vehicle).

FEATURES: The imminent crash avoidance warning should provide a visual display along with an auditory or tactile display (see Sections 2.4.1, 2.4.6, 2.5.3, and 2.6).

[*See specific 4.4.1 comments in Appendix A*]
[*See General Comments in Appendix C*]

4.4.2 CAUTIONARY CRASH AVOIDANCE WARNINGS.

Multiple levels of cautionary crash avoidance warnings should be provided to alert the driver to a cautionary crash avoidance situation which does not meet the criteria of an imminent crash avoidance warning situation.

DEFINITION OF CAUTIONARY CRASH AVOIDANCE SITUATION: Cautionary crash avoidance warnings should indicate that some corrective braking action is likely required to avoid collision with a detected object.

FEATURES: Cautionary crash avoidance warnings should provide either visual, auditory, or tactile warning displays (see Sections 2.4.2, 2.4.6, 2.5.3, and 2.6). Visual warnings, in combination with auditory or tactile warnings, are preferred. It is desirable that at least one mode of warning convey relative changes in distance- or time-based information, increasing in perceived urgency as the vehicle nears the target object. There should be a readily discriminable, qualitative change in the signal between the lower- and higher-level cautionary warning zones even when relative distance or time-based information is provided. Higher-level cautionary warnings should indicate a higher degree of perceived urgency than lower-level cautionary warnings. Likewise, all cautionary warnings should be readily discriminable from the imminent crash avoidance warning if an imminent crash avoidance warning is present on the device.

For an object detected within the cautionary crash avoidance warning zones, there is a reasonable chance that, if the driver has not noticed the object, some corrective action needs to be taken. There are many instances during the backing maneuver where relatively close proximity to an object is intentional (e.g. parallel parking, backing out of a parking space) and the higher-level cautionary warning will be signaled. To avoid confusion, all cautionary crash avoidance warnings should be readily discriminable from the imminent crash avoidance warning, if an imminent crash avoidance warning is present on the device.

Visual warning displays have the advantage of being less intrusive and less annoying to the driver. Considering the repetitive nature of many backing maneuvers (e.g., backing out of a driveway) and the frequency with which some higher-level warnings are likely to be presented (e.g., while parallel parking) visual warnings may be advantageous. Properly placed visual warning displays would also encourage drivers to directly look toward the backing pathway and to use their mirrors while backing.

The more intrusive modes of warning such as auditory and tactile displays also have several advantages. It is not known precisely where drivers look while backing, and these locations will vary somewhat depending on the situation. These types of warnings, unlike visual displays, do not require the driver to be looking at a specific location in order to get his or her attention. Also, because backing maneuvers are restricted situations, utilizing very little time related to the overall driving task, these modes may be less annoying to the driver because they are presented for only a short time. Conflicts with other warnings are less of a concern during backing maneuvers, and there is also less of a concern about abrupt driver actions which may occur when drivers react to these intrusive warning modes.

It is desirable to have relative distance- or time-based information, rather than an indication of the presence of an object within a general zone, as this provides important crash avoidance information. For instance, several current systems have warnings which increase in flash/beep rate, acoustic frequency (i.e., pitch), and/or intensity as the rear of the vehicle approaches the target. One system provides a bar-type LED display in which more LEDs are lit as the target is approached. However, such information should be augmented by an additional change in the warning signal as the distance- or time-to-target moves from a lower-level cautionary warning zone into a higher-level cautionary warning zone. Consider a device which represents a decreasing distance-to-target measure by an increasing acoustic beep rate. When the situation changes from a lower-level to a higher-level warning situation, then there should be a noticeable, abrupt "jump" in the beep rate, pitch, etc. of the presented signal. This change in the signal will provide additional information to the driver regarding the object's proximity to the vehicle.

[*See specific 4.4.2 comments in Appendix A*]
[*See Review and Discussion Issue #3, Comment 10 in Appendix B*]
[*See General Comments in Appendix C*]

4.5 DETECTION ZONE COVERAGE AREA.

4.5.1 REAR ZONE COVERAGE AREA.

The detection zone should span the entire width of the vehicle. The zone should extend to a distance of at least (TBD) feet to the rear of the vehicle. Sensors should be able to detect appropriate targets immediately behind the vehicle, even if the targets are adjacent to the rear of the vehicle or are below the mounted height of the sensor. The zone should be continuous, with no "holes" in the coverage area. The detector field should reliably capture small narrow targets in all likely positions to the rear of the vehicle.

The detector zone should extend from the rear bumper of the vehicle to a specified distance to the rear of the vehicle. This distance, which will be specified at a later date, is a function of the braking reaction time of the driver, as well as the backing speed of the vehicle. No data are available on brake reaction time for backing drivers. Backing speeds are typically 5 mph or less. No data have been found that indicate the distribution of distances between the backing vehicle and the collision object at the start of the backing maneuver. Without such information, the desired area of coverage cannot be well defined. The field should not extend too far to the rear of the vehicle, as this would result in a proliferation of nuisance alarms. However, the field must be large enough to allow the driver to make a corrective action. Backing crashes involving children, especially in driveways or parking lots, often involve toddlers crawling or sitting immediately behind vehicles (Walker, 1993). Thus, objects already adjacent to the rear bumper should be detected by the sensors, as well as objects near the ground which are immediately below the edge of the rear bumper.

Systems intended for use as parking aids by large commercial trucks often emit a narrow radius sensor beam which is reflected off of non-porous objects, such as loading docks, to monitor distance-to-target during the backing maneuver. Devices which are intended for use as safety warning devices, however, must provide a more thorough detection zone coverage of the rear area of the vehicle than those provided by systems intended solely as distance measuring devices. There should not be any "holes" in the detection area between sensors. Children, pedalcyclists, fixed posts, etc. should be detected by the sensors at any location within the detection zone, including rear and lateral areas. If drivers come to rely on sensors with incomplete coverage, there could be a tendency to assume it is safe to back up when no warning is present.

[*See specific 4.5.1 comments in Appendix A*]

4.5.2 LATERAL ZONE COVERAGE AREA.

The device may provide lateral coverage beyond the side of the vehicle and/or along the side of the vehicle near the rear bumper (distances TBD).

Lateral detector field coverage, in addition to coverage directly to the rear of the vehicle, will provide the driver with additional information and increase the amount of time that the driver has to react to avoid a potential crash. In a review of over 400 Police Accident Reports (PARs), COMSIS studied in detail 52 cases involving backing crashes (COMSIS and Castle Rock Consultants, 1992). Of 41 backing crashes involving fixed objects, pedestrians, pedalcyclists, or parked or slowly moving vehicles, 32 percent had the point of impact at the left or right rear fender, and another 10 percent had the point of impact to the side or front fender. Such situations arise when a pedestrian or cyclist moves into the pathway of a car from the side or when the vehicle is turning while backing. Without lateral detector field coverage, only objects already in the straight pathway of the vehicle are detected. Detection zones along the sides of the vehicle near the rear bumper would also provide assistance in parking and maneuvering around barriers.

The degree of lateral and corner coverage that is optimal is not known. If the coverage area is too narrow, critical objects may not be detected in time to avoid collision. However, if the coverage area is too wide, the frequent occurrence of nuisance alarms may lead to driver annoyance and possible disarming of the system.

4.6 INDICATION OF LOCATION OF HAZARD.

4.6.1 IN LIGHT/PASSENGER VEHICLES.

For light/passenger vehicles (e.g., passenger cars, passenger vans, pick-up trucks), location indicators are not recommended.

> Because of the relatively small area of limited visibility to the rear of passenger vehicles, providing location indicators is not necessary. A simple indication of the presence of an object within the detection zone provides sufficient information to the driver. Because driver response to the backing warning is generally not directional (e.g., turn right, turn left), additional cues as to the location of the detected object relative to the rear of the vehicle (e.g., left, center, right) will only clutter the display and are not likely to influence driver response.

4.6.2 IN HEAVY/COMMERCIAL VEHICLES.

For heavy/commercial vehicles (e.g., commercial trucks, buses), location indicators (e.g., arrow displays, spatially-localized acoustic signals, voice messages) may be used to provide an indication of the location of the target object within the rear detection zone (e.g., left, center, right). Locational indicators may be used for all levels of warning.

> Large commercial vehicles may benefit from having additional information regarding the location of the detected object relative to the rear of the vehicle (e.g., left, center, right). Based on the location indicators, the driver will know, for instance, which direction to steer and drive forward in order to realign the vehicle so that the object can be seen in the side view mirror, so that the backing maneuver can proceed.

[*See specific 4.6.2 comments in Appendix A*]

4.7 TERMINATION OF WARNINGS.

4.7.1 AUTOMATIC TERMINATION OF WARNINGS.

4.7.1.1 Imminent Crash Avoidance Warning Displays.

Visual warning displays should be automatically terminated only when the location of the target object no longer meets the defining criteria for imminent crash avoidance warnings. Auditory or tactile warnings should be automatically terminated only when the location of the target object no longer meets the defining criteria for imminent crash avoidance warnings and may be temporarily terminated when the vehicle comes to a complete stop. Temporarily terminated warnings should reactivate if the vehicle begins backing and a warning situation still exists. A driver corrective action sensed by the system should not automatically terminate the warning. Refer to Section 4.7.2 for transient manual override guidelines.

For the backup warning device, the only time that the imminent crash avoidance visual warning should be automatically terminated is when the location of the target object no longer meets the imminent crash avoidance situation. The visual display should remain on whenever an object is detected, even if the vehicle is completely stopped. This will provide the driver with information concerning objects in the backing pathway prior to starting the maneuver. In order to decrease the annoyance level, it is permissible to allow the auditory and tactile warnings to be automatically terminated when the vehicle comes to a complete stop. However, the system sensing a driver corrective action (e.g., braking) may not be enough to justify automatic termination of the auditory or tactile warning. Drivers often have their foot on the brake pedal while backing and may intermittently apply pressure to the brake, even when not reacting to some warning. Additionally, the driver may have his or her attention diverted away from the visual display, in which case the redundant auditory or tactile warning becomes the primary means of capturing the driver's attention. Thus, allowing the system to terminate a warning based on driver corrective actions may inadvertently silence a necessary warning.

[*See specific 4.7.1.1 comments in Appendix A*]

4.7.1.2 Cautionary Crash Avoidance Warning Displays.
Visual warning displays should be automatically terminated only when the location of the target object no longer meets the defining criteria for cautionary crash avoidance warnings. Auditory or tactile warnings should be automatically terminated only when the location of the target object no longer meets the defining criteria for cautionary warnings and may be temporarily terminated after the vehicle comes to a complete stop. A driver corrective action sensed by the system (e.g., braking) is sufficient to temporarily terminate lower-level cautionary warnings. Sensing driver corrective actions is not sufficient to temporarily terminate higher-level cautionary warnings. Temporarily terminated warnings should reactivate whenever the vehicle begins backing and a warning situation exists. Refer to Section 4.7.2 for transient manual override guidelines.

For backup warning devices, cautionary crash avoidance warnings should be automatically terminated when there is no longer an object detected in the cautionary warning detection zone. In order to decrease annoyance, it is permissible to allow auditory and tactile warnings to be automatically terminated when the vehicle comes to a complete stop. However, the visual display should remain on whenever an object is detected, even if the vehicle is completely stopped. This will provide the driver with information concerning objects in the backing pathway prior to starting the maneuver. The system sensing a driver corrective action (e.g., braking) is also sufficient to justify temporary termination of lower-level auditory and tactile cautionary warnings. However, for higher-level cautionary warnings, driver corrective actions should not terminate these warnings. Drivers often have their foot on the brake pedal while backing and may intermittently apply pressure to the brake, even when not reacting to some warning. Thus, allowing the system to terminate a higher-level cautionary warning based on driver corrective actions may inadvertently silence a necessary warning.

4.7.2 TRANSIENT MANUAL OVERRIDE OF WARNINGS.

4.7.2.1 Visual Warning Displays.

Transient manual override controls should not be provided for visual displays.

Because of the possibility of an unexpected object being present in the pathway of the vehicle (e.g., child playing behind the vehicle), a transient manual override should not completely disarm the system. Visual displays should continue to function, even when auditory or tactile displays are disarmed so that the driver will continue to have feedback from the system concerning objects in the pathway of the vehicle.

4.7.2.2 Auditory and Tactile Warning Displays.

Transient manual override controls for auditory and tactile warning displays should not be provided for imminent crash avoidance warnings. Transient manual override controls are permitted for lower- and higher-level cautionary warnings only if there is a redundant visual display.

Common objects along the driveway such as trees, other vehicles, the wall of the house, and the recognition of the roadway as an object when the rear of the vehicle dips down at the end of the driveway could set off repetitious nuisance alarms while backing. Because of the more invasive nature of audible displays, they may become annoying to the driver during such maneuvers. Therefore, a manual override feature should be provided for the driver to temporarily disarm this type of display. However, the manual override should be cancelled each time the vehicle is placed out of reverse gear.

[*See specific 4.7.2.2 comments in Appendix A*]

4.8 DETECTOR SENSITIVITY ADJUSTMENT.

Controls/adjustments should meet all requirements for controls/adjustments in Section 2.7.

[*See General Comments in Appendix C*]

4.8.1 REAR ZONE COVERAGE AREA.

No controls should be provided which permit adjustment of the sensitivity of the sensors covering the rear detection zone of the vehicle.

The detection zone directly to the rear of the vehicle should not be manually controlled by the driver because of the critical nature of detecting all objects directly in the vehicle's pathway.

4.8.2 LATERAL ZONE COVERAGE AREA.

A control may be provided to permit adjustment of the sensitivity of the sensors covering the detection zone lateral to the vehicle (i.e., width of the detector field) for transient periods of time. The device should default to the preestablished default lateral coverage area each time the vehicle is placed out of reverse gear.

To minimize the occurrence of false alarms, the driver may be allowed to periodically control the width of the lateral field. This would avoid, for instance, repetitious detection of objects alongside a driveway (e.g., trees, wall of the house, other vehicles) while backing. However, when the vehicle is placed out of reverse gear, the backing system should automatically reset to the default lateral coverage area to prevent the system from inadvertently remaining on the least sensitive sensor settings.

5.0 DRIVER ALERTNESS MONITORING DEVICES.

The following guidelines should be used in conjunction with the general guidelines in Section 2.0.

5.1 DEVICE APPLICATION.

This section addresses driver alertness monitoring devices. These devices are intended to warn the driver when the driver's alertness is impaired below a level that is no longer consistent with safe operation of the vehicle. The device should temporarily enhance driver alertness to avoid a crash situation, but it is not intended to be used by the driver as a means to stay awake over long periods of driving. This application is for conditions of enroute driving and is distinguished from devices that attempt to identify driver impairment at trip onset.

Driver alertness monitors attempt to detect periods of driver impairment due to drowsiness or other lapses of alertness. The impaired state might be brought on by fatigue, sleep deprivation, medication, drugs of abuse, alcohol, naturally occurring stressors, or environmental factors. Research indicates that drivers are good at recognizing their drowsy condition but are not good at recognizing the point of sleep onset. These devices provide the driver with an aid for recognizing that condition.

Driver alertness monitoring devices should be distinguished from those devices that attempt to identify impaired drivers at trip onset and perhaps even immobilize the vehicle to prevent an unfit driver from endangering himself or others. Driver alertness monitors are intended to diagnose driver alertness impairments and signal drivers to progressive or critical alertness lapses, allowing the driver to avoid a more hazardous situation.

Although many physiological measures have been related to driver alertness, most have been limited to R&D environments. There are several commercially available eye closure monitors and head nod detectors, however, and at least one behavioral task "alerter." The current generation of commercial monitors are stand-alone devices, and are not integrated with other crash avoidance warning systems or vehicle subsystems. These devices must be physically attached to or worn by the driver and, because of intrusiveness, are not ideal for the driving environment. These first generation devices will serve to introduce this technology to the public, support field validation studies, and test the marketplace for this particular type of device.

[*See specific 5.1 comments in Appendix A*]

5.2 OPERATIONAL CHARACTERISTICS.

5.2.1 ALERTNESS SENSING METHODS.

Remote or proximal sensing methods may be used to monitor driver alertness. Remote sensing systems are preferred to proximal sensing systems.

Two methods of sensing driver alertness are currently available. These include remote sensing devices, which have no physical contact with the driver, and proximal sensing devices, which must be physically attached to or worn by the driver. Remote sensing devices include systems which use CCD cameras to monitor blink rate. In addition, there are measures under development which can unobtrusively measure physiological measures of alertness. In addition to these direct methods of monitoring, systems exist which indirectly monitor driver alertness by assessing driver behavior. These systems evaluate current driving behavior against, past profiles or template driving patterns to determine if driver impairment has occurred. Proximal devices employ a broad range of indicators of sleep onset and driver impairment, including head nods, as well as various physiological measures of alertness to trigger an alert.

[*See specific 5.2.1 comments in Appendix A*]

5.2.2 DEVICE ACTIVATION.

5.2.2.1 Remote Sensing Devices.

Remote sensing devices should be automatically activated whenever the engine is on and the vehicle is placed in forward gear. The driver should be able to manually activate or deactivate the device at any time while driving by means of an ON/OFF switch. The device should automatically deactivate whenever the vehicle is placed out of forward gear or the engine is turned off.

During states of drowsiness or driver impairment, drivers will tend to be more forgetful and prone to errors. The devices should be turned on automatically to prevent the driver from forgetting to activate the system. In addition, by limiting the activation of the device to times when the vehicle is in forward gear, the number of false alarms will be reduced. This will increase the validity of the device to the drivers. The driver will also need the capability to turn the system off during times when it is inappropriate to measure drowsiness.

[*See specific 5.2.2.1 comments in Appendix A*]

5.2.2.2 Proximal Sensing Devices.

Devices which are attached to or worn by the driver (e.g., headsets, eyeglass attachments) should be turned on manually by the driver by means of an ON/OFF switch. Ideally the device should be activated only when the vehicle is placed in forward gear. The driver should be able to manually activate or deactivate the device at any time while driving by means of an ON/OFF switch. The device should automatically deactivate, ideally, whenever the vehicle is placed out of forward gear or the engine is turned off.

By recommending that the vehicle be in forward gear, some nuisance alarms can be eliminated. When the vehicle is temporarily placed in "Park" gear, for instance, nuisance alarms may sound due to driver inactivity. In such situations, the driver should not be required to override the resulting alarms. Nor should the driver have to temporarily turn the system off and be depended on to remember to turn the system back on when driving resumes. However, since current devices are "stand alone", do not sense vehicle status, and would require some form of communication with the vehicle, this provision is unlikely with the current level of technology.

Ideally, all driver alertness monitors should be automatically activated without requiring a positive driver action to turn the system on. However, automatically activating devices that must be physically attached to or worn by the driver (e.g., headsets, eyeglass attachments) would lead to a proliferation of false alarms when the system was not being worn. Because of the intrusive nature of such devices, drivers are not likely to wear them on every trip (i.e., in-town driving for only a short time, when well-rested, etc.). Annoyance factors associated with false alarms or with having to deactivate a device which is automatically activated each time the vehicle is turned on may lead to the driver disarming the device permanently.

[*See specific 5.2.2.2 comments in Appendix A*]

5.2.3 DEVICE CALIBRATION.

The device should be self-calibrating. If the device is not self-calibrating, driver requirements for calibrating the device should be minimized and should be as simple and intuitive as possible.

By their nature, driver alertness monitoring devices based on physiological measures will require calibration to accommodate individual driver differences, often on a trip by trip basis. Drivers will not use the device if it requires lengthy or difficult calibration procedures. If the device is to be accepted and used consistently, the device calibration should preferably be automatic. If automatic calibration is not possible, then the procedure for calibration should be as simple and straightforward as possible.

5.2.3.1 Frequency of Calibration.

Calibration of remote devices should occur each time the engine is turned on. Calibration of proximal devices should occur each time the device is turned on.If a body worn device is used only by a single individual, it may be possible to calibrate less frequently.

5.2.4 DEVICE FITTING/MOUNTING INTERFACE.

Design of the device should minimize needs to wear or physically connect the system to the driver. Remote sensing systems are ideal. For systems which are physically worn by the driver, discomfort should be minimized, including during periods of extended use. Manual adjustment requirements for optimal fit should be minimized.

The need to have sensors in immediate proximity to the driver's body is a major limitation to current products, although various less obtrusive methods are being explored such as video image processing or analysis of vehicle control actions. Given that the sensor must be attached to or worn by the driver, the fatigue application demands that the device remain comfortable and unobtrusive even during periods of extended use, and that the device remain in adjustment.

Many of the current and proposed systems require some minor adjustments to properly aim the sensing device or ensure contact of sensors with the driver's skin. Depending on the sensing method, such adjustments may be a "necessary evil" of the system, since allowing the driver to adjust the device provides an opportunity for the driver to adjust the device incorrectly and potentially render the device ineffective and dangerous.

Some methods of installation, fitting, or adjustment for physiological measurement devices can be especially complex in current applications. In fact, some require specially trained personnel to properly install sensors and adjust sensor placement. This high degree of training or accuracy is unacceptable for a consumer product and, thus, should be avoided.

[*See specific 5.2.4 comments in Appendix A*]

5.3 WARNING DISPLAY LOCATION.

5.3.1 AUDITORY SOUND SOURCE LOCATION.

Sound sources for presenting auditory warnings should be located so that they do not direct the driver's attention away from the roadway ahead, including sound sources located within a headset or otherwise near the driver's ear. Locating speakers only in passenger side of the dash, only in the passenger door, etc. should be avoided.

Drivers who are in a drowsy state will likely be more startled by an auditory warning than an alert driver, and sleep inertia may cause the driver to be temporarily disoriented. Thus every effort should be made to minimize confusion. Speakers should be located so that the auditory warnings do not distract the driver's attention from the roadway ahead.

[*See specific 5.3.1 comments in Appendix A*]

5.3.2 VISUAL WARNING DISPLAY LOCATION.

Visual warnings should be located within 15 degrees of the driver's normal line of sight of the roadway ahead.

[*See specific 5.3.2 comments in Appendix A*]

5.3.3 TACTILE WARNING DISPLAY LOCATION.

Tactile display warnings should be located so that they do not direct the driver's attention away from the roadway ahead. Locating tactile warnings within a headset, the driver's seat, or the steering column are preferred. Locating tactile warnings within foot pedals is discouraged.

A drowsy driver will likely be more startled by a tactile warning than an alert driver, and may be temporarily disoriented. Thus, every effort should be made to minimize confusion and to locate displays such that the warnings do not distract the driver's attention away from the roadway ahead. Because a drowsy driver may not have his foot planted firmly on the accelerator or brake, and because such a location may be quite confusing to an impaired driver, tactile displays located foot pedals are not recommended. However, tactile displays within a headset, the driver's seat, or the steering column would likely be readily detectable by the driver. Additionally, for cautionary warnings, tactile indicators have the advantage of privacy and social acceptability, since the output is directed only to the driver instead of being broadcast among all passengers.

[*See specific 5.3.3 comments in Appendix A*]

5.4 LEVELS OF WARNING.

The device should provide at least an imminent crash avoidance warning. A lower-level cautionary warning, in addition to the imminent crash avoidance warning, is strongly preferred.

Most currently available driver alertness monitoring systems provide only a single warning related to a critical level of impairment (e.g., imminent crash avoidance situation). For the current systems, this may mean a head nod or lengthy eye closure to indicate sleep onset. Unfortunately, this high-level event occurs later in the monitoring process than is ideal. It is preferable to have a low-level cautionary alert before the point that more severe indicators of sleep onset are present so that the driver can take some action to correct the situation (e.g., pull off the road and rest) before the imminent crash avoidance situation arises.

A driver who has been alerted by an imminent crash avoidance warning will likely be in such a deep state of drowsiness that he or she will suffer from symptoms similar to those of "sleep inertia". Sleep inertia adversely affects simple reaction time, short-term memory, and cognitive performance, thus hindering accurate or controlled responses (Tepas and Paley, 1992). These factors greatly affect the driver's ability to regain control of the vehicle after being alerted to his or her drowsy state. Thus, providing cautionary warnings to the driver to indicate a state of reduced alertness would hopefully encourage the driver to correct the condition before the more critical imminent situation presents itself.

Although still in the research and development stages, several approaches to detecting early signs of driver drowsiness, based on driver performance and/or driver physiological state, are currently being explored. Driver performance measures being investigated include changes in steering adjustments, increased speed variability, and slowed reaction times, among others. Blink rate, heart rate variability, and EEG drowsiness patterns are among the driver physiological measures currently being explored (Mackie and Wylie, 1991).

[*See specific 5.4 comments in Appendix A*]

5.4.1 IMMINENT CRASH AVOIDANCE WARNINGS.

Imminent crash avoidance warnings should be provided to alert the driver to an imminent crash avoidance situation. Imminent crash avoidance warnings for driver alertness monitoring devices should comply with Sections 2.4.1 and 2.5.2.

DEFINITION OF IMMINENT CRASH AVOIDANCE SITUATION: An imminent crash avoidance situation exists when an obvious indicator of sleep onset (e.g., head nod, lengthy eye closure) or some other reliable imminent precursor to sleep (e.g., EMG, EOG, or other physiological measure) is detected.

Imminent crash avoidance warnings should be activated when some physiological condition reaches a predetermined threshold which indicates that the driver is failing to appropriately monitor the environment and/or control the vehicle. For example, an imminent crash avoidance warning may be activated when the driver closes his eyes for some criterion length of time, when a sustained head nod is detected, or when some other positive physiological indicant of sleep onset is detected. Thus, the imminent crash warning here is associated with the most distinct and near-term danger (e.g., eyes closed), but not necessarily in conjunction with an immediate collision hazard or driving behavior.

FEATURES: The imminent crash avoidance warning should provide an auditory or tactile primary display. A supplementary or redundant visual, auditory, or tactile mode of display different from the primary mode should also be provided (acoustic tones and speech warnings are considered to be similar modes of display). Visual displays are permitted only as supplemental or redundant imminent crash avoidance warning displays and should not be used as primary warning displays. The warning should be rapidly and reliably detected by a drowsy driver.

Visual displays should not be relied on as primary displays for imminent crash avoidance warnings. It is possible that no matter where the visual display is located, the driver may not see the display. However, an auditory or tactile warning would not be so easily blocked out by a drowsy driver and would serve as a more effective means of capturing the driver's attention. Display redundancy overcomes problems associated with a single mode of warning that does not capture the driver's attention (i.e., auditory warning not being heard in a noisy environment, tactile warning not being felt on a rough roadway).

[*See specific 5.4.1 comments in Appendix A*]

5.4.1.1 Warning Ambiguity.

At least one display mode of the imminent crash avoidance warning should obviously identify the warning as a driver alertness warning (i.e., by placement in headset or by speech or visual warning descriptor such as "DROWSY").

At least one mode of warning should be presented to the driver such that its meaning is immediately obvious to the driver. Unlike many other crash avoidance warning devices, alertness monitoring device warnings are not based on target-specific information (e.g., vehicle in blind spot) and are not specific to a given driving situation (e.g., following lead vehicle too closely). If the driver is not actually feeling drowsy or even anticipating sleep onset, an alertness warning which is presented globally, without any other identifying information, may be treated unknowingly as a false alarm from another crash avoidance device in the vehicle or mistaken as a signal from some other source. Therefore, the meaning of at least one mode of the warning must be made obvious to the driver. This may be accomplished, for instance, by localizing an auditory or tactile warning display within a headset which is used for monitoring alertness, providing a descriptive visual display (e.g., "DROWSY") in conjunction with the primary display, or providing a similarly descriptive speech warning to the driver.

[*See specific 5.4.1.1 comments in Appendix A*]

5.4.1.2 Passenger Awareness of Warning.

At least one mode of the imminent crash avoidance warning should be readily detectable by

passengers in the vehicle.

There may be implications associated with methods of output (e.g., global auditory warnings, visual displays) that provide understandable feedback to passengers regarding the level of alertness of the driver. There may be positive implications in situations where the driver is unwilling or unable to recognize impairment. A warning that is noticeable by others in the vehicle will alert the passengers to the driver's severely impaired condition so that they can encourage him or her to stop driving.

[*See specific 5.4.1.2 comments in Appendix A*]

5.4.1.3 Desired Driver Reaction to Warning.
The warning should induce rapid recovery of awareness, at least temporarily arousing the driver from the drowsy state so that he or she is able to recover vehicle control. The warning should not induce inappropriate reactions such as startle, uncontrolled maneuvers, or disorientation.

It is important that driver response to the warning is appropriate for safe and effective avoidance of crash situations. The imminent crash avoidance warning should alert the driver to the impaired condition and should effectively arouse the driver so that he or she is able to immediately recover vehicle control and safely pull off of the roadway if necessary.

[*See specific 5.4.1.3 comments in Appendix A*]

5.4.2 CAUTIONARY CRASH AVOIDANCE WARNINGS.
Cautionary crash avoidance warnings should be provided to alert the driver to a cautionary crash avoidance situation which does not meet the criteria of an imminent crash avoidance warning situation.

DEFINITION OF CAUTIONARY CRASH AVOIDANCE SITUATION: A cautionary crash avoidance situation exists whenever a state of decreased driver alertness is detected prior to indications of sleep onset.

Cautionary warning algorithm logic may take one of several forms. Cautionary warning criteria may be more sensitive than imminent crash avoidance warning criteria (i.e., eyes closed for a shorter period of time), they may be based on trend analysis of indicators over time (i.e., number and duration of blinks, blink strength variation, steering wheel control input), or they may be based on direct measures of physiological or behavioral indices that are correlated with precursors of sleep.

FEATURES: Cautionary warnings should provide an auditory or tactile primary display. Supplementary or redundant visual, auditory, or tactile modes of display different from the primary display are recommended (acoustic tones and speech warnings are considered to be similar modes of display). Graded warnings which are proportional to the level of measured alertness are permissible. The warning should be rapidly and reliably detected by a drowsy driver.

Visual displays should not be relied on as primary displays for cautionary warnings. It is possible that no matter where the visual display is located, the driver may not see the display. However, an auditory or tactile warning would not be so easily blocked out by a drowsy driver and would serve as a more effective means of capturing the driver's attention.

Unlike imminent crash avoidance warnings, cautionary warnings do not require redundant displays for auditory or tactile primary warnings. However, such redundancy is preferred since dual modes of output will likely increase driver arousal capabilities. Redundancy overcomes problems associated with a single mode of warning not capturing the driver's attention (i.e., auditory warning not being heard in a noisy environment, tactile warning not being felt on a rough roadway). Because of the more intrusive nature of the dual modes, the redundancy of the warnings may also more effectively encourage the driver to stop driving until the impaired state is corrected.

Graded warnings may be used if the device is capable of measuring relative levels of alertness or the rate of warning presentation. If used, such warnings should increase in intensity as the level of alertness decreases. Although no graded warnings are currently being employed in driver alertness warning devices, the additional feedback would provide useful information to the driver concerning his or her actual level of alertness and would hopefully help to encourage the driver to stop driving until a safe level of alertness is restored.

5.4.2.1 Warning Ambiguity.

The cautionary warning display should obviously identify the warning as a driver alertness warning (e.g., by placement in headset or by speech or visual warning descriptor such as "DROWSY"). (See Section 5.4.1.1 for rationale.)

[*See General Comments in Appendix C*]

5.4.2.2 Passenger Awareness of Warning.

Cautionary warnings are not required to be detectable by passengers in the vehicle.

There may be implications associated with methods of output (e.g., global auditory warnings, visual displays) that provide understandable feedback to passengers regarding the level of alertness of the driver. There may be positive implications in imminent crash avoidance situations where the driver is unwilling or unable to recognize impairment and, thus, puts the lives of his passengers in danger. However, for low levels of impairment, alerting other passengers to the driver's condition is not as critical. Cautionary warnings will occur more frequently, and problems associated with annoyance or social embarrassment will be greater. The trade-off in using a more public warning display is unclear.

[*See specific 5.4.2.2 comments in Appendix A*]

5.4.2.3 Desired Driver Reaction to Warning.

The driver should be informed of the condition of impaired alertness and should stop driving as soon as is safe. The warning should not induce inappropriate reactions such as startle, uncontrolled maneuvers, or disorientation.

Cautionary warnings should be designed to heighten the driver's awareness of his state of alertness. These warnings should act as a confirmation to the driver that impaired alertness has, in fact, been detected and that continued driving may be hazardous. Because of the temporal nature of these warnings, they should be thought of as awareness enhancers. The appropriate response to a cautionary warning should be for the driver to stop driving as soon as is safe until his or her level of alertness is restored.

5.5 TERMINATION OF WARNINGS.

5.5.1 AUTOMATIC TERMINATION OF WARNINGS.

Warning displays should be automatically terminated only when the triggering condition no longer exists. All initiated warnings should be presented for at least 1 second prior to termination. Warning displays should be reactivated immediately upon detection of an impaired state of alertness, even if the warning has just been presented to the driver.

Driver alertness warnings are intended to encourage the driver to acknowledge his or her impaired state of alertness and to respond appropriately. Thus, the warning should remain in effect until that response is made (e.g., driver opens eyes, lifts head to erect position) and the triggering condition no longer exists, or until the driver makes a positive action to manually override the warning. After initiation, all warnings should be presented for a duration of at least 1 second in order to reduce driver confusion. This gives the driver adequate time to identify the source of the warning.

Alertness follows a somewhat cyclical pattern where a person experiences various degrees of arousal. Even though a person may temporarily be brought out of a drowsy state by a warning, he or she may quickly return to this drowsy state without realizing it. Therefore, a warning that has been automatically terminated should be immediately reactivated upon any subsequent detection of a drowsy state.

[*See specific 5.5.1 comments in Appendix A*]

5.5.2 TRANSIENT MANUAL OVERRIDE OF WARNINGS.

5.5.2.1 Imminent Crash Avoidance Warnings.

No transient manual override controls should be provided for imminent crash avoidance warnings.

Imminent crash avoidance warnings should be presented only when indicators of imminent sleep onset are detected (e.g., head nod, extended eye closure). Because of the criticality of these situations, the warning should continue to be presented until the triggering condition is corrected. Thus, the driver should not be able to manually override the imminent crash avoidance warning. In such a drowsy state, the driver may instinctively attempt to quiet the warning if given the opportunity, similar to a person habitually turning off an alarm clock in the morning and going back to sleep without even consciously knowing that the alarm has sounded. Such automaticity has been observed with railroad engineers during long trips. This type of automatic reaction by the driver to silence an imminent crash avoidance warning without recognizing or heeding its message will ultimately result in an ineffective warning device.

[*See specific 5.5.2.1 comments in Appendix A*]

5.5.2.2 Cautionary Crash Avoidance Warnings.

A transient manual override control for cautionary warnings should be provided. Some positive driver action should be required to activate the manual override control. The transient manual override should temporarily silence cautionary auditory and tactile warnings for a period of 3 to 5 minutes. If an imminent crash avoidance situation arises while the cautionary warning override is in effect, the imminent crash avoidance warning should take precedence and should be immediately presented to the driver.

With auditory and tactile indicators, manually overriding the warning is an important capability because it removes a source of potential distraction from the driver's environment, enabling total attention to be focused on the warning's triggering condition. However, consideration must be given to possible automatic driver reactions to overriding the auditory or tactile warning. If the action required to implement the override is made too simple for the driver, attempts to silence the warnings will become automatic, resulting in an ineffective warning device. However, by requiring a more complex input to engage the override control, the automaticity problem would likely be alleviated. Such design efforts may include requiring more refined motor skills for control activation (i.e., pressing a button which is normally flush with its associated panel) or requiring two tasks to be performed in sequence (i.e., pushing in a knob and turning the knob clockwise).

Silencing the alarm temporarily (approximately 3 to 5 minutes) will give the driver a chance to deal with the situation without being continually distracted by possible subsequent cautionary warnings. By reducing annoyance problems, such an override will hopefully prevent drivers from turning off the device altogether. If an imminent crash avoidance situation is detected at any time during the override silencing of the cautionary warning, the imminent crash avoidance warning should be immediately presented to the driver. Thus, the transient override should only temporarily disable cautionary warning displays, but not the sensors themselves.

[*See specific 5.5.2.2 comments in Appendix A*]

5.6 DETECTOR SENSITIVITY ADJUSTMENT.

Controls/adjustments should meet all requirements for controls/adjustments in Section 2.7.

[*See General Comments in Appendix C*]

5.6.1 IMMINENT CRASH AVOIDANCE WARNINGS.

For devices with high quality self-calibration capabilities, sensitivity adjustment should not be provided for imminent crash avoidance warnings. For devices with less than optimal automatic calibration capabilities, sensitivity adjustment parameters provided to the driver should be minimized.

[*See specific 5.6.1 comments in Appendix A*]

5.6.2 CAUTIONARY CRASH AVOIDANCE WARNINGS.

Sensitivity adjustment is permissible for cautionary warnings for devices both with and without automatic calibration capabilities. Sensitivity should not be adjustable below some preestablished threshold (threshold will be device-specific, depending on measurement techniques and parameters).

Some current systems require adjustment of sensor sensitivity to ensure effective operation. For example, head nod detection systems require adjustment of the mercury switch orientation to reduce false alarms and to ensure that head droop is detected. By their nature, physiological driver alertness monitoring sensors will require calibration to accommodate individual driver differences, often on a trip-by-trip basis. If a body worn device is used only by a single individual, it may be possible to calibrate less frequently.

6.0 HEADWAY WARNING DEVICES.

The following guidelines should be used in conjunction with the general guidelines in Section 2.0.

[*See specific 6.0 comments in Appendix A*]

6.1 DEVICE APPLICATION.

This section addresses headway warning devices which are intended to alert the driver travelling on a roadway to the presence of a slower moving vehicle, stopped vehicle, or object in the forward pathway of the vehicle. These devices are also intended to alert the driver to dangerously short headway situations. Headway warning devices should provide an alert to the driver when objects are in the path of the vehicle, but should preclude alerts from vehicles in adjacent lanes.

6.2 DEVICE ACTIVATION.

The system should be automatically activated whenever the ignition switch is turned on and the vehicle is placed in forward gear. It is permissible to preclude warning signals if the vehicle is travelling below a speed of 10 mph.

> Drivers should not be required to activate the system each time the vehicle ignition switch is turned on. This function should be provided automatically. By requiring the vehicle to be in forward gear, some nuisance warnings can be eliminated. To preclude a proliferation of nuisance and false warnings in bumper-to-bumper traffic or while parking the vehicle, deactivating the device below some minimum speed of travel (e.g., 10 mph) provides another means for further eliminating inappropriate warnings (see Section 6.5).

[*See specific 6.2 comments in Appendix A*]

6.3 PRIMARY VISUAL DISPLAY LOCATION.

The primary visual display for all levels of warning should be located at or within 15 degrees of the driver's normal line of sight of the roadway ahead. Positions at or near the front windshield are preferred. The primary display should be distinct from all other instrumentation clusters. Additional visual displays may supplement, but not replace, this primary visual indicator.

> Visual signals are more detectable when located close to the line of sight. Most human factors guidelines indicate that important visual information should be located within 30 degrees of the normal line of sight, with the most critical information being located within 15 degrees of the line of sight (MIL-STD-1472D; Boff and Lincoln, 1988). Location also inherently provides an unambiguous directional cue to the driver and must meet two additional criteria. First, the display must serve to pull the inattentive driver's attention to the

roadway ahead so that the driver can respond to the hazard. Second, it must not draw the attention of a driver who is attending to the roadway ahead away from that area.

[*See specific 6.3 comments in Appendix A*]

6.4 LEVELS OF WARNING.

The device should provide at least two levels of warning, an imminent crash avoidance warning and a cautionary crash avoidance warning.

[*See specific 6.4 comments in Appendix A*]

6.4.1 IMMINENT CRASH AVOIDANCE WARNINGS.

Imminent crash avoidance warnings should be provided to alert the driver to an imminent crash avoidance situation. Imminent crash avoidance warnings for headway warning devices should comply with Section 2.4.1 and 2.5.2

DEFINITION OF IMMINENT CRASH AVOIDANCE SITUATION: An imminent crash avoidance situation exists when a vehicle or target object is sensed in the detection zone and time-to-collision is 3 to 5 seconds or less or headway to the target object is 1.0 to 1.5 seconds or less.

Vehicles will frequently be in the headway detection zone of the following vehicle without providing the threat of an imminent collision. Such a threat only occurs when the following vehicle begins to approach the lead vehicle at a rate of closure which could potentially cause a collision, or when the following vehicle in a lead-vehicle-moving (LVM) situation is following too closely, with little or no closing rate. In order to protect its uniqueness and effectiveness, the imminent crash warning should not be used to shape "proper" driver behavior, but rather only to warn an unaware driver when some vehicle control action is required.

The 3-5 second time-to-collision criterion is based both on driver response time requirements and on the discrimination of intentional from unintentional headway situations. Response time requirements were estimated based on the AASHTO (1990) model for stopping sight distance. The model assumes that the distance required to brake to a stop in reaction to an obstacle ahead is the summation of two components: 1) the distance traveled during the perception-reaction time (PRT) (i.e. time required to detect, recognize, decide, and initiate a response); and 2) the distance required to decelerate to a complete stop.

In applying the AASHTO formula, a value of 2.0 seconds was used for driver PRT rather than the 2.5 second value used by AASHTO for highway design equations. The value of 2.0 seconds encompasses most drivers in most relevant on-road brake studies (Triggs and Harris, 1982; Lerner *et al.*, 1990). Furthermore, it is reasonable to assume that the most extreme values observed in field research are due to long PRT from less attentive drivers. The use of in-vehicle warning signals will likely preclude most of these extremes. Using the AASHTO formula along with a 2.0 second PRT, and assuming a closing rate of 50 mph, the required stopping distance translates to a required warning time of 4.8 seconds. This value is somewhat conservative in that AASHTO uses a wet roadway coefficient of friction in its braking model. Janssen and Nilsson (1990), citing data from Van der Horst (1984), argue that a 4 second or less time to collision separates the case where the driver has unintentionally gotten into a situation which he or she judges dangerous versus those situations where the driver feels that he or she is in control. Together, these considerations suggest that the time-to-collision threshold for an imminent crash avoidance warning should probably be in the 3-5 second range. This recommendation should be more strictly defined with further research.

The criterion for a warning based on constant headway separation is more ambiguous, since no hazard event actually exists until there is a closing rate detected between the two vehicles. What constitutes being "too close" to react in time is strongly dependent on the assumptions one makes about the possible sudden deceleration rate of the lead vehicle. The recommendation of 1.0 - 1.5 seconds is based on two aspects of driver behavior. First, data on following headways (Evans and Wasielewski, 1982) shows that those headways tend to be quite brief, with a mean of 1.32 seconds. The distribution of headway times rises steeply at around one second. Second, when braking responses in reaction to a lead vehicle's brake lamps were measured (Triggs and Harris, 1982), it was found that very few drivers reacted by braking if the headway exceeded 1.4 seconds. Based on these considerations, a threshold that precludes excessive nuisance warnings, and that is perceived as credible for requiring an immediate brake response will be in the 1.0 -1.5 second range.

FEATURES: The imminent crash avoidance warning should provide a visual display along with an auditory or tactile display (see Sections 2.4.1, 2.4.6, 2.5.3, and 2.6).

[*See specific 6.4.1 comments in Appendix A*]
[*See General Comments in Appendix C*]

6.4.2 CAUTIONARY CRASH AVOIDANCE WARNINGS.

Cautionary crash avoidance warnings should be provided to alert the driver to a cautionary crash avoidance situation which does not meet the criteria of an imminent crash avoidance warning situation.

DEFINITION OF CAUTIONARY CRASH AVOIDANCE SITUATION: A cautionary crash avoidance situation exists when a vehicle is sensed in the detection zone ahead of the vehicle and 1) time-to-collision is greater than that defined for the imminent crash avoidance situation (e.g., 3 to 5 seconds), but no greater than 10 to 14 seconds, or 2) headway to the target object is greater than that defined for the imminent crash avoidance situation (e.g., 1.0 to 1.5 seconds), but no greater than 2 to 3 seconds. Feedback may be provided to the driver for situations in which time-to-collision exceeds 10 to 14 seconds, or headway exceeds 2 to 3 seconds. Such feedback should be considered informational rather than a cautionary crash avoidance warning.

The cautionary crash avoidance warning is designed to alert the driver to a situation which requires immediate attention. Therefore, the model should allow time for the driver to recognize the hazard and to evaluate alternative strategies for dealing with the hazard, while precluding the need for an emergency response. A commonly used highway design model for this situation is the AASHTO (1990) formula for the minimum sight distance for decision sight distance situations. The AASHTO decision sight distance lane change maneuver, defined as the distance required for a driver to detect an unexpected hazard in a visually cluttered environment, recognize the hazard, and formulate an appropriate response to the hazard, provides an appropriate model for this application. According to AASHTO (1990) conditions, such a maneuver requires a total of 10 to 14 seconds to complete. The headway time of 2-3 seconds is based on rules of thumb from driving manuals and safety recommendations. Evans (1991) points out that most driving manuals recommend *at least* two seconds of headway. Optimal time-to-collision and headway values may actually be less than the upper limits which have been recommended.

The use of informational displays or graded cautionary warning displays may provide benefits to the headway warning system. Horowitz and Dingus (1992) make a case for using graded warnings which provide advanced information to the driver. The authors propose a system based on time-to-collision which provides a warning graded from mild to severe, based on the severity of the hazard situation. These authors argue that the use of the graded system would not only decrease the number of severe warnings, but would also decrease the negative effects of startle responses.

Horowitz and Dingus (1992) also identify a number of potential advantages of displaying supplemental headway information. The authors recommend a system which provides a headway display. The headway display would serve three functions: provide the driver with feedback on his headway maintenance, assist the driver in maintaining a safe headway, and provide the visual portion of the headway warning system. The authors speculate that the driver may come to associate the display with the lead vehicle and, thus, shorten the reaction time when a quick response is required. A system which provides this information must not require or promote significant head down time during imminent crash warning conditions. The trade off between this potential for shortened response time and the increase in time spent with the driver's eyes and attention away from the road must be evaluated analytically and empirically.

FEATURES: The cautionary crash avoidance warning should provide a visual display to the driver. Auditory or tactile warning displays may also be provided (see Sections 2.4.2, 2.4.6, 2.5.3, and 2.6). Cautionary warnings should capture the driver's attention, but should not annoy the driver, even with frequent presentation.

Vehicles may frequently enter the cautionary warning criterion area during normal driving. However, the inattentive driver should be somehow alerted to the presence of a vehicle in this range. There is a fundamental trade-off between the device being able to attract the attention of the inattentive driver, while minimizing annoyance for the alert and observant driver. (It should be noted that each individual driver will likely pass into and out of attentive stages within a single driving trip.) Auditory and tactile warning modes would probably be more effective in alerting the inattentive driver to a hazardous situation. However, the annoyance factors associated with many auditory or tactile cautionary warnings would likely lead to the attentive driver turning off the system if cautionary warnings were presented in an intrusive manner. Therefore, auditory and tactile cautionary warnings should adequately capture the driver's attention, but should also be nonintrusive so as not to cause annoyance with frequent presentation. Even if auditory or tactile cautionary warnings are employed, however, a visual warning is required in order to accommodate situations where multiple simultaneous warnings must be presented (see Section 2.3.3).

[*See specific 6.4.2 comments in Appendix A*]

6.5 CONTROL OF FALSE AND NUISANCE WARNINGS.

It is permissible to preclude warning signals if the vehicle is travelling below a speed of 10 mph. The device should <u>not</u> be deactivated at higher closing rates as a method of reducing opposing traffic false and nuisance warnings.

Bumper-to-bumper traffic, parking or other driving situations may lead to a proliferation of headway nuisance warnings. By allowing the device to be deactivated below some minimum speed (e.g., 10 mph), many of these inappropriate warnings will be eliminated. However, the minimum criterion speed should not be so low that it precludes alarms on arterial roads, a major source of front-to-rear collisions. Based on a recent study (Knipling, Mironer, Hendricks, Tijerina, Everson, Allen, and Wilson, 1993), 34% of the "under control" lead vehicle rear-end crashes in the 1990-91 GES occurred at speeds of 15 mph or less. Twenty-five per cent of the crashes occurred at speeds of 10 mph or less. Based on this data, a minimum operating speed of 10 mph for headway warning systems will encompass at least 75% of the crashes.

Some current devices preclude warnings when the closing rate between the following and lead vehicle exceeds some criterion level, in order to reduce false and nuisance warnings triggered by opposing traffic. However, using these maximum closing rate thresholds will adversely affect the ability of the system to detect lead-vehicle-stationary (LVS) crash situations where the following vehicle is moving at a high rate of speed. Several studies show that LVS rear-end collisions outnumber LVM collisions by a ratio of over 2:1 (Knipling *et al.*, 1993). In addition, the initial phase of the current project identified that 47% of police reported crashes fit the general scenario of a lead vehicle stopped on an arterial road. Besides the LVS situation, the use of a maximum closing rate limit would also result in the headway warning device missing head-on collision situations.

[*See specific 6.5 comments in Appendix A*]

6.6 DETECTION ZONE COVERAGE AREA.

The system should allow for the detection of objects in the path of the vehicle, but should not be activated by vehicles or objects in adjacent lanes. The maximum range may vary relative to subject vehicle speed (i.e., increase range as speed of the subject vehicle increases). The detectors should reliably capture small potential target vehicles (e.g., motorcycles) in all likely lane positions ahead of the vehicle.

[*See specific 6.6 comments in Appendix A*]

6.7 INDICATION OF DIRECTION OF HAZARD.

6.7.1 VISUAL WARNING DISPLAYS.

The device should provide a visual warning display within the driver's normal line of sight of the roadway ahead to indicate the general direction of the hazard for all warnings (see Section 6.3).

Using a visual display located in the general direction of the hazard provides a means for rapidly guiding visual search and indicating an appropriate driving response. Because an indication of a lead vehicle in the detection zone may occur very frequently, visual information alone is preferable for the cautionary crash avoidance situation, in order to minimize annoyance and intrusion from auditory or tactile sources. Given that the driver becomes familiar with a visual directional signal for the cautionary warning situation, this well-established stimulus-response relationship should also be carried over to the more critical imminent crash situation. Finally, when multiple imminent crash avoidance hazards exist at the same time, directional visual information is required, as discussed in Section 2.3.3 of these Guidelines. Taken together, these considerations require that a visual indication of the general direction of the hazard be provided for imminent crash avoidance warnings and that, in most instances, visual displays are preferred for cautionary warnings.

[*See General Comments in Appendix C*]

6.7.2 AUDITORY WARNING DISPLAYS.

Auditory warning displays (e.g., spatially-localized acoustic signals, voice messages) may be used to indicate the direction of the hazard. Auditory warnings should appear to emanate from the front of the vehicle.

[*See specific 6.7.2 comments in Appendix A*]

6.7.3 TACTILE WARNING DISPLAYS.

Tactile warning displays may be used to indicate the direction of the hazard. The tactile display should consistently direct the driver's attention to the roadway ahead.

Driver response to directional tactile signals has received little attention. Some human factors design references (Boff and Lincoln, 1988) discourage the use of tactile signals as disruptive or difficult to control. Ongoing research under the European Community DRIVE project has included tactile signals but has reported little information on the driver's immediate reaction to the signals and has provided some suggestion of poorer user acceptance of such tactile warning signals (Janssen and Nilsson, 1990). Pending some demonstration of added benefits of directional warning modalities other than visual and auditory, driver response to specific tactile cues should be thoroughly tested prior to their implementation in warning devices.

[*See specific 6.7.3 comments in Appendix A*]

6.8 TERMINATION OF WARNINGS.

6.8.1 AUTOMATIC TERMINATION OF WARNINGS.

6.8.1.1 Imminent Crash Avoidance Warning Displays.

Imminent crash avoidance warning displays should be automatically terminated only when the location of the target object no longer meets the defining criteria for an imminent crash avoidance situation.

The imminent crash avoidance warning is intended to induce the driver to respond immediately and should remain in effect until that response is made or is no longer required. Normally, this will be indicated by the cessation of the defining conditions for the imminent crash warning situation. While there may be direct indicators of a vehicle maneuver (e.g., braking) which indicate that the driver has responded to the warning, terminating the warning is not recommended until the hazardous situation no longer exists. A driver may merely be "covering" the brake, or a driver may respond to the warning rather than the situation. In such a situation, if the associated warning were terminated, the driver may stop implementing a necessary corrective maneuver.

[*See specific 6.8.1.1 comments in Appendix A*]

6.8.1.2 Cautionary Crash Avoidance Warning Displays.
The cautionary crash avoidance warning visual display should remain on at all times when a cautionary situation exists. The warning should be automatically terminated only when the cautionary situation no longer exists.

For the headway warning device, the only time that the cautionary visual warning should be automatically terminated is when the cautionary situation no longer is detected. The visual display should remain on whenever a cautionary situation exists. This will provide the driver with information concerning headway status, even if the driver is attentive to the driving situation.

6.9 CONTROLS/ADJUSTMENTS.
Single sensitivity adjustments which control only one of the parameters, or integrate several parameters, are recommended. No more than three individual controls should be provided. Controls/adjustments should meet all requirements in Section 2.7.

The number of adjustment controls provided to the driver should be limited so that the driver can easily and effectively "tune" the system while driving. Field experience with military systems (e.g., M1 Abrams main battle tank thermal sight) indicates that operators have difficulty in making more than two or three continuous adjustments on the same display. The exact algorithms for integrating sensitivity adjustments must be tested and evaluated empirically.

[*See General Comments in Appendix C*]

6.9.1 SENSITIVITY ADJUSTMENT.
A control may be provided to allow the driver to adjust the sensitivity of the sensor to reduce false and nuisance alarm rates, and to accommodate a variety of driving conditions and driving styles. The particular parameters (e.g., sensor range, return signal strength, sensor field of view, etc.) should be transparent to the driver.

As identified in the initial phase of this project a number of the current headway warning devices provide the capability to adjust various parameters of the system in order to "tune" the system to the driving environment. Given the anticipated false and nuisance alarm potential of the headway warning systems this "tuning" may be required for driver acceptance of the devices. However, if sensitivity adjustments are incorporated into the design of the system, the operation and effects of these adjustments must be obvious to the driver.

[*See specific 6.9.1 comments in Appendix A*]

6.9.2 CRITERIA ADJUSTMENT.
A control may be provided to allow the driver to adjust the headway and time-to-collision criteria within a limited range. The driver should not be allowed to adjust the device below a minimum level to ensure effectiveness.

While these guidelines recognize the need for adjustment in current devices, little research has been found which provides data on the driver's ability to effectively adjust this type of system. The limits of adjustability need to be determined empirically, based on drivers' abilities to make these adjustments without significantly degrading the overall performance of the system.

7.0 REFERENCES\BIBLIOGRAPHY

American Association of State Highway and Transportation Officials (AASHTO). (1990). *A policy on geometric design of highways and streets*. Washington, D.C.: AASHTO.

AAA Foundation for Traffic Safety. (1985). A report on the determination and evaluation of the role of fatigue in heavy truck accidents. *Transportation Research and Marketing*, Washington, D.C.: AAA Foundation for Traffic Safety.

American Association of Retired Persons. (1992). *Older driver skill assessment and resource guide: Creating mobility choices*. Washington, D.C.: Author.

American Industrial Hygiene Association. (1966). *Industrial noise manual* (2nd ed.). Detroit: American Industrial Hygiene Association.

Angiolillo, J. S., and Roberts, L. A. (1991). What makes a manual look easy to use? *Proceedings of the Human Factors Society 35th Annual Meeting,* 222-224.

Antin, J. F., Lauretta, D. J., and Wolf, L. D. (1991). The intensity of auditory warning tones in the automobile environment: Detection and preference evaluations. *Applied Ergonomics, 22*(1), 13-19.

Begault, D. R., and Wenzel, E. M. (1990). *Techniques and applications for binaural sound manipulation in human-machine interfaces*. Moffett Field, CA: National Aeronautics and Space Administration, Ames Research Center.

Berson, B. L., Po-Chedley, D. A., Boucek, G. P., Hanson, D. C., Leffler, M. F., and Wasson, R. L. (1981). *Aircraft alerting systems standardization study: Volume II - Aircraft alerting system design guidelines* (Report No. FAA-RD-81-38-II). Washington, D.C.: Federal Aviation Administration.

Bertone, C. M. (1982). Human factors considerations in the development of a voice warning system for helicopters. *Behavioral Objectives in Aviation Automated Systems Symposium* (Paper No. 821407) (pp. 133-142). Warrendale, PA: Society of Automotive Engineers.

Birren, J., Woods, A., and Williams, M. (1980). Behavioral slowing with age: Causes, organization, and consequences. In L. Poon, Ed., *Aging in the 1980s*. Washington, D.C.: American Psychological Association.

Blauert, J. (1969/1970). Sound localization in the median plane. *Acoustica, 22,* 206-213.

Bliss, J. P., Gilson, R., and Rinalducci, E. J. (1992). *Human factors alert/display standards and guidelines in aviation* (Report submitted to COMSIS Corporation, Silver Spring, MD). Orlando, FL: University of Central Florida, Center for Applied Human Factors in Aviation and Department of Psychology.

Boff, K., and Lincoln, J. (1988). *Engineering data compendium: Human perception and performance*. Wright-Patterson Air Force Base, Ohio: Harry G. Armstrong Aerospace Medical Research Laboratory.

Brown, J. E., Bertone, C. M., and Obermeyer, R. W. (1968). *Army aircraft warning system study* (U. S. Army Technical Memorandum 6-689). Aberdeen Proving Ground, MD: U. S. Army Engineering Laboratories.

Butler, F., Manaker, E., and Obert-Thorn, W. (1981). *Investigation of a voice synthesis system for the F-14 aircraft* (Report No. ACT-81-001). Bethpage, NY: Grumman Aerospace Corporation.

Cann, M. T., Vercruyssen, M., and Hancock, P. A. (1990). Age and the elderly internal clock: Further evidence for a fundamentally slowed CNS. *Proceedings of the Human Factors Society 34th Annual Meeting*, 158-162.

Christ, R. E. (1975). Review and analysis of color coding research for visual displays. *Human Factors*, *17*(6), 542-570.

COMSIS Corporation and Castle Rock Consultants. (1992). *Survey of warning systems of in-vehicle crash avoidance warning systems: Human factors considerations* (Task I Interim Report, NHTSA Project No. DTNH22-91-C-07004). Silver Spring, MD: COMSIS Corporation.

Davis, D., Schweizer, N., Parosh, A., Lieberman, D., and Apter, Y. (1990). *Measurement of the minimum reaction time for braking vehicles*. Israel: Wingate Institute for Physical Education and Sport.

Dewar, R. (1993). Warning: Hazardous road signals ahead. *Ergonomics in Design*, July, 26-31.

Dingus, T.A., Hardee, H.L., and Wierwille, W.W. (1987). Development of models for on-board detection of driver impairment. *Accident Analysis and Prevention, 19*(4), 271-283.

DOE-STD-HFAC. (a.k.a. DOE/NELLNL/NSSP). (1992). *Human factors engineering design criteria*. Washington, D.C.: Department of Energy.

Easterby, R. S. (1967). Perceptual organization in static displays for man/machine systems.

Ergonomics, 10, 195-205.

Easterby, R. S. (1970). The perception of symbols for machine displays. *Ergonomics, 13*(1), 149-158.

Edworthy, J., Loxely, S., and Dennis, I. (1991). Improving warning design: Relationship between warning sound parameters and perceived urgency. *Human Factors, 33*(2), 205-231.

Evans, L., and Wasielewski, P. (1982). Do accident involved drivers exhibit riskier everyday driving behavior? *Accident Analysis and Prevention, 14,* 57-64.

FAA-D-2494/b. *Technical instruction book manuscript: Electronic, electrical, and mechanical equipment, requirements for preparation of manuscript and production of books*. Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration.

Federal Aviation Administration. (1990). Introduction to TCAS II. Washington, D.C.: U. S. Department of Transportation, Federal Aviation Administration.

Federal Highway Administration. (1988). *Manual on uniform traffic control devices for streets and highways*. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration.

Finnegan, P., and Green, P. (1990). *The time to change lanes: A literature review.* (UMTRI-90-34, IVHS TR-90-13).

Fozard, J. L., Vercruyssen, M., Reynolds, S., and Hancock, P. A. (1990). Longitudinal analysis of age-related slowing: BLSA reaction time data. *Proceedings of the Human Factors Society 34th Annual Meeting*, 163-167.

Gardner-Bonneau, D. J. (1989). *Script evaluation for an american express credit card authorization application*. Proprietary report to American Express Travel-Related Services Company, Phoenix, AZ.

Gilson, R. (1992). Personal communication with Neil Lerner, COMSIS Corporation. Orlando, FL: University of Central Florida, Center for Applied Human Factors in Aviation and Department of Psychology.

Goldhaber, G. M., and Weaver, C. (1968). Listener comprehension of compressed speech when the difficulty, rate of presentation, and sex of the listener are varied. *Speech Monographs, 35*, 20-25.

Gribbons, W. M. (1992). Organization by design: Some implications for structuring information. *Technical Writing and Communication, 22,* 57-75.

Hancock, P. A., and Parasuraman, R. (1992). Human factors and safety in the design of intelligent vehicle-highway systems (IVHS). *Journal of Safety Research, 23*, 181-198.

Hardee, H.L., Dingus, T.A., and Wierwille, W.W. (1986). Driver drowsiness detection using subsidiary task and driving performance measures. *Proceedings of the Human Factors Society 30th Annual Meeting*, 398-402.

Hart, S. G., and Simpson, C. A. (1976). Effects of linguistic redundancy on synthesized cockpit warning message comprehension and concurrent time estimation. *Proceedings of the Twelfth Annual Conference on Manual Control*, 309-321.

Haworth, N. and Vulcan, P. (1991). Testing of commercially available fatigue monitors. From Le Maintien De La Vigilance Dans Les Transports, M. Vallet (ed.). *Transports et Communication 34*(81-103) (ISBN 2-86878-059-8). Caen: Paradigme.

Heglin, H. J. (1973). *NAVSHIPS display illumination design guide: II. human factors* (NELC/TD223). San Diego: Naval Electronics Laboratory Center.

Helander, M. G. (1987). Design of visual displays. In G. Salvendy, Ed., *Handbook of human factors* (pp. 507-548). New York: Wiley.

Hooper, K., and McGee, H. (1983). Driver perception-reaction time: Are revisions to current specification values in order? *Transportation Research Record 904*. Washington, D.C.: Transportation Research Board.

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.

Hostetter, R., McGee, H., Crowley, K., Sequin, E., and Dauber, G. (1986). Improved Perception-Reaction Time Information for Intersection Sight Distance (FHWA/RD-87/015). Washington, D.C.: Federal Highway Administration.

Hulbert, S. (1972). Effects of driver fatigue. In T.W. Forbes (ed.) *Human factors in highway traffic safety research*. New York: Wiley and Sons.

Institute of Transportation Engineers. (1992). *Traffic engineering handbook* (4th Ed). Englewood Cliffs, New Jersey: Prentice Hall.

Itoi, A., Cilveti, R., Voth, M., Dantz, B., Gupta, A., and Dement, W. (1993). *Can drivers avoid falling asleep at the wheel?* Washington, D.C.: AAA Foundation for Traffic Safety.

Janssen, W., and Nilsson, L. (1990). *An experimental evaluation of in-vehicle collision* *avoidance systems*. The Netherlands: University of Groningen, Traffic Research Centre.

Janssen, W. (1989). *The impact of collision avoidance systems on driver behavior and traffic safety: Preliminaries to studies within the GIDS project*. The Netherlands: University of Groningen, Traffic Research Centre.

Janssen, W. H., and Nilsson, L. (1990). *An experimental evaluation of in-vehicle collision avoidance systems* (Rep. No. GIDS/MAN2). Haren, The Netherlands: University of Groningen, Traffic Research Centre.

Johansson, G., and Rumar, K. (1971). Drivers' brake reaction times. *Human Factors*, *13*, 23-27.

Kantowitz, B. H., and Sorkin, R. D. (1983). *Human factors: Understanding people/system relationships*. New York: Wiley.

Knipling, R.R. (1993). IVHS technologies applied to collision avoidance: Perspectives on six target crash types and countermeasures. *Proceedings of the IVHS AMERICA 1993 Annual Meeting*.

Knipling, R., Mironer, M., Hendricks, D.L., Tijerina, L., Everson, J., Allen, J.C., and Wilson, C. (1993). *Assessment of IVHS countermeasures for collision avoidance: Rear-end crashes*. NHTSA Technical Report DOT HS 807 995. Washington, D.C.: National Highway Traffic Safety Administration, Office of Crash Avoidance Research.

Knipling, R. (1992). Personal communication with Neil Lerner, COMSIS Corporation. Washington, D.C: National Highway Traffic Safety Administration, Office of Crash Avoidance Research.

Korteling, J. (1990). Perception-response speed and driving capabilities of brain-damaged and older drivers. *Human Factors, 32*, 95-108.

Kryter, K. (1972). Speech communication. In H. Van Cott and R. Kinkade (Eds.), *Human engineering guide to equipment design*. Washington, D.C.: U. S. Government Printing Office.

Lerner, N. D., Huey, R. W., Jr., McGee, H. W., and Sullivan, A. J. (1992). *Older driver perception-reaction time for intersection sight distance and object detection* (Contract DTFH 61-90-C-00038, Task D and E Working Paper). Washington, D.C.: U. S. DOT, Federal Highway Administration.

Lerner, N. D., Ratte, D. J., Huey, R. W., Jr., McGee, H. W., and Hussain, S. F. (1990).

Literature review: Older driver perception-reaction time (Contract DTFH 61-90-C-00038, Task B Working Paper). Washington, D.C.: U. S. DOT, Federal Highway Administration.

Lilliboe, M. L. (1963). *Final report: Evaluation of Astropower, inc. auditory information display installed in the VA-3B airplane* (Technical Report No. ST 31-22R-63, AD831823). Patuxent River, MD: U.S. Naval Air Station, Naval Air Test Center.

Mackie, R.R. and Wylie, C.D., (1991). Countermeasures to loss of alertness in motor vehicle drivers: A taxonomy and evaluation. *Proceedings of the Human Factors Society 35th Annual Meeting*, 1149-1153.

Makous, J. C., and Middlebrooks, J. C. (1990). Two dimensional sound localization by human listeners. *The Journal of the Acoustical Society of America, 87*(5), 2188-2200.

May, M. (1993, May-June). Hearing is believing. *Technology Review,* 229.

McFadden, D., and Pasanen, E. G. (1976). Lateralization at high frequencies based on interaural time differences. *The Journal of the Acoustical Society of America, 59,* 634-639.

McGehee, D. V., Dingus, T. A., and Horowitz, A. D. (1992). The potential value of a front-to-rear-end collision warning system based on factors of driver behavior, visual perception and brake reaction time. *Proceedings of the Human Factors Society 36th Annual Meeting,* 1003-1005.

McKelvey, F. X., Maleck, T. L., Stamatiadis, N., and Hardy, D. K. (1988). Highway accidents and the older driver. *Transportation Research Record 1172* (pp. 47-57). Washington, D.C.: National Research Council.

MIL-HDBK-759B. (1992). *Human factors engineering design for army material*. Washington, D.C.: Department of Defense.

MIL-M-GCSFUI. (1991). *Manuals, interactive electronic technical: General content, style, format, and user-interaction requirements*. Philadelphia, PA: Navy Publishing and Printing Office.

MIL-STD-490A. (1985). *Specification practices*. Philadelphia, PA: Navy Publishing and Printing Office.

MIL-STD-962B. (1988). *Preparation of military standards, handbooks, and bulletins*. Philadelphia, PA: Navy Publishing and Printing Office.

MIL-STD-1472D. (1989). *Human engineering design criteria for military systems, equipment and facilities*. Washington, D.C.: Department of Defense.

Mills, A. W. (1958). On the minimal audible angle. *The Journal of the Acoustical Society of America*, *30*, 237-246.

Moore, T. J. (1987). Speech technology in the cockpit. In R. S. Jensen, Ed., *Aviation Psychology*. Brookfield: Gower.

Morgan, C. T., Cook, J. S., Chapanis, A., and Lund, M. W. (Eds.). (1963). *Human engineering guide to equipment design*. New York: McGraw-Hill.

Mortimer, R. G. (1988). Rear-end crashes. In G. A. Peters and B. J. Peters, Eds., *Automotive Engineering and Litigation* (Vol. 2, pp. 275-306). New York: Garland Law Publishing.

Mortimer, R. G., and Kupec, J. D. (1983). Scaling of flash rate for a decelerating signal. *Human Factors*, *25*(3), 313-318.

National Transportation Safety Board. (1990). *Safety study: Fatigue, alcohol, other drugs, and medical factors in fatal-to-the-driver heavy truck crashes (vol. 1)* (NTSB No. PB90-917002) Washington, D.C.: Author.

Nilsson, L., Alm, H., and Janssen, W. (1991). *Collision avoidance systems - effects of different levels of task allocation on driver behaviour*. The Netherlands: University of Groningen, Traffic Research Centre.

Nixon, C. W., Anderson, T. R., and Moore, T. J. (1986). The perception of synthetic speech in noise. In R. Salvi, D. Henderson, R. P. Hammernik, and V. Coletti, Eds., *Basic and applied aspects of noise induced hearing loss*. New York: Plenum.

Norman, D. (1988). The design of everyday things. New York: Doubleday/Currency.

NUREG-0700. (1981). *Guidelines for control room design reviews*. Washington, D.C.: U.S. Nuclear Regulatory Commission.

Olson, P. L. (1989). *Driver perception response time* (SAE Paper 8900731). Detroit: Society of Automotive Engineers.

Olson, P., Cleveland, D., Fancher, P., Kostyniuk, L., and Schneider, L. (1984). *Parameters affecting stopping sight distance* (NCHRP Report 270). Washington, D.C.: Transportation Research Board.

Olson, P., and Sivak, M. (1986). Perception-response time to unexpected roadway hazards. *Human Factors, 28*, 91-96.

Patterson, R. D. (1982). *Guidelines for auditory warning systems on civil aircraft* (Paper 82017). London, UK: Civil Aviation Authority.

Peio, K., and Dolan, N. (1992). *Monitor and control software (MCS) display coding standard final report* (Contract No. DTFA03-86-C-00018). Final report prepared for the Federal Aviation Administration Technical Center, Advanced Systems Technology Branch (ACD-350), Pomona, NJ.

Peterson, A., and Gross, E., Jr. (1978). *Handbook of noise measurement* (8th ed.). New Concord, MA: General Radio Co.

Randle, R. J., Larsen, W. E., and Williams, D. H. (1980). *Some human factors issues in the development and evaluation of cockpit alerting and warning systems* (Report No. NASA-RP-1055). Moffett Field, CA: NASA-Ames Research Center.

Reynolds, R. F., White, R. M. Jr., and Hilgendorf, R. I. (1972). Detection and recognition of colored signal lights. *Human Factors, 14*(3), 227-236.

Rosson, M. B. (1985). *Listener training for speech output applications* (Report No. RC11029 #49529). Yorktown Heights, NY: IBM Thomas J. Watson Research Center.

SAE ARP 450. (1971). *Flight deck visual, audible and tactile signals*. Warrendale, PA: Society of Automotive Engineers.

Salthouse, T. (1985). Speed of behavior and its implications for cognition. In J. Birren and K. Schaie, Eds., *Handbook of the psychology of aging*. New York: Van Nostrand Reinhold.

Salvendy, G., (1982). *Handbook of industrial engineering*. New York: John Wiley and Sons.

Sanders, M. S., and McCormick, E. J. (1993). *Human factors in engineering and design* (7th ed.). New York: McGraw-Hill.

Simpson, H., and Casey, S. M. (1988). *Developing effective user documentation*. New York: McGraw-Hill.

Simpson, C. A., and Marchionda-Frost, K. (1984). Synthesized speech rate and pitch effects on intelligibility of warning messages for pilots. *Human Factors, 26*, 509-517.

Simpson, C. A., and Williams, D. (1980). Response time effects of alerting tone and semantic context for synthesized voice cockpit warnings. *Human Factors, 22*, 319-320.

Sivak, M., Olson, P. L., and Farmer, K. M. (1982). Radar measured reaction time of unalerted drivers to brake signals. *Perceptual and Motor Skills, 55*, 594.

Sorkin, D. (1987). Design of auditory and tactile displays. In G. Salvendy, Ed., *Handbook of human factors* (pp. 549-576). New York: Wiley.

Stokes, A.F., Wickens, C.D., and Kite, K. (1990). *Display technology: Human factors concepts*. Warrendale, PA: Society of Automotive Engineers, Inc.

Summala, H. (1981). Driver/vehicle steering response latencies. *Human Factors, 23*, 683-692.

Taeuber, C. (1983). America in transition: An aging society. *Current Population Reports, Special Studies Series P-23*, No. 128). Washington, D.C.: Bureau of the Census, U. S. Department of Commerce.

Teichner, W. R. (1954). Recent studies of simple reaction time. *Psychological Bulletin*, *51,* 128-149.

Teichner, W. H., and Krebs, M. J. (1972). Estimating the detectability of target luminances. *Human Factors, 14*(6), 511-519.

Tepas, D.I., and Paley, M.J. (1992). Managing alertness and fatigue in advanced IVHS. *Proceedings of the IVHS America 1992 Annual Meeting*, 785-790.

Thomas, J. C., Rosson, M. B., and Chodorow, M. (1985). Human factors in synthetic speech. In B. Shackel, Ed., *Proceedings of Human-Computer Interaction - Interact '84* (pp. 219-224). Amsterdam: Elsevier.

Tolin, P. (1984). An information transmission of signal flash rate discriminability. *Human Factors*, *26*(4), 489-493.

Treat, J.R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E., Stansifer, R.L., Castellan, N.J. (1977). *Tri-level study of the causes of traffic accidents* (DOT HS 805 085). Washington, D.C.: National Highway Traffic Safety Administration.

Triggs, T., and Harris, W. G. (1982). *Reaction time of drivers to road stimuli* (Human Factors Report HFR-12). Melbourne, Australia: Monash University.

Tun, P. A., Wingfield, A., Stine, E. A., and Mecsas, C. (1992). Rapid speech processing and divided attention: Processing rate versus processing resources as an explanation of age effects. *Psychology & Aging*, *7*(4), 546-550.

Van Cott, H. P., and Kinkade, R. G. (1972). *Human engineering guide to equipment design*. Washington, D.C.: McGraw-Hill.

Veitengruber, J. E., Boucek, G. P. Jr., and Smith, W. D. (1977). *Aircraft alerting systems criteria study (vol. I): Collation and analysis of aircraft alerting systems data* (Rep. No. FAA-RD-76-222-I). Washington, D.C.: Federal Aviation Administration.

Verrillo, R. T. (1966). Effects of contactor area on vibration threshold. *Journal of the Acoustical Society of America*, *35*, 1962-1966.

Walker, J. (1993). New perspectives on non-traffic collisions involving child-pedestrians. Submitted to *37th Annual Proceedings of the Association for the Advancement of Automotive Medicine*.

Wang, J.S., and Knipling, R. (1993). *Lane change/merge crashes: Problem size assessment and statistical description*. (In press). Washington, DC: National Highway Traffic Safety Administration, Office of Crash Avoidance Research.

Wheale, J. (1980). Pilot opinion of flight deck warning systems. In D. Oborne and J. Levis, Eds., *Human Factors in Transport Research: Volume 1*. New York: Academic Press.

Wickens, C. D. (1992). *Engineering psychology and human performance* (2nd ed.). New York: HarperCollins.

Woodson, W. E., and Conover, D. W. (1964). *Human engineering guide for equipment designers*. Berkeley, CA: University of California Press.

Woodson, W. E., Tillman, B., and Tillman, P. (1992). *Human factors design handbook.* (2nd Ed.). New York: McGraw-Hill.

Wright, P. (1983). Manual dexterity: A user-oriented approach to creating computer documentation. *CHI 1983 Conference Proceedings*, 11-18.

APPENDIX A

COMMENTS BY GUIDELINE SECTION

Appendix A contains specific comments on the guidelines by professionals in the field of IVHS. This appendix is organized by guideline section. If a specific section is not represented in this appendix, no comment was received.

Section 1.0 Introduction

1.2 Objective

Comment 1:

What do you mean to "illuminate" the state of human factors...?

1.4 Scope of the Document

Comment 1:

The Guidelines should state early in the document exactly how the driver is expected to respond given alternative situations triggering activation of each device.

Section 2.0 General Guidelines

2.1.1.1 Application of Power

Comment 1:

A counter-example: A drunk driver should not be allowed to put the vehicle in motion.

Comment 2:

The authors recommend that power be applied to the warning device when the vehicle ignition switch is turned on, even if the device is capable of being turned off manually during vehicle operation. They state that this application of power should place the device into the "standby" mode of operation. The authors reason that drivers cannot be relied on to turn on their crash avoidance warning devices each time they turn on the vehicle ignition, so these devices must be turned on automatically. In response to this, I must ask what the purpose is for implementing a standby mode which cannot be used by the driver? From the driver's perspective, isn't this the same as having the system completely deactivated? It would make more sense to have the system be completely activated when the ignition switch is turned on, but allow the driver to deactivate it manually at any point in time following activation (as recommended in section 2.1.1.3 "Termination of Power".) This will also save the driver from performing an extra step in activating the system.

Comment 3:

Eliminate sentences #2 and #4.

Comment 4:

What activates?

Comment 5:

Why?

2.1.1.2 Activation for Use

Comment 1:

Delete this section. Either on or off.

2.1.1.3 Termination of Power

Comment 1:

Display on/off.

Comment 2:

Tradeoff: A driver may forget the system has been turned off and have a false sense of security that modifies driver behavior, driving strategies, or risk taking.

Comment 3:

Powered or standby vs. activated when applicable are design details. Auto operational when needed is requirement.

2.1.2.1 Built-In Diagnostic Testing

Comment 1:

"Built-In Diagnostic Testing" says that all devices that fail should automatically be placed into a failure mode. Section 2.5.4 is referenced. This referenced section does not deal with failure mode, but rather says that device status should be clearly displayed. I agree that degraded conditions should be displayed. Consider adding statement in that failure status should be clearly displayed. This will make the intent of the reference to Section 2.5.4 clear.

Comment 2:

The driver should be notified of a failure (see Section 2.5.4) in addition to or in lieu of a standby mode.

Comment 3:

With BIDT available, there should be a power termination when the system is down or faulty.

Comment 4:

Eliminate sentence "All devices that pass diagnostic testing ...."

2.1.2.2 Failure of Multi-Sensor Devices

Comment 1:

Last sentence of rationale is not consistent with the guideline.

Comment 2:

Last sentence of rationale, delete "even if the remaining sensors continue to operate properly". Add, "and the device should be fully disabled."

2.1.2.3 Warning Test Display

Comment 1:

Reset to maximum after each ignition cycle?

Comment 2:

Reset to nominal on power up for ambient light levels limit range.

Comment 3:

The driver should be provided with the capability of testing each warning display manually at any time during vehicle operation. The display should be activated for a sufficient time period to permit manual adjustment of display intensity. A potential problem exists in that a driver, attending to the adjustment of the display brightness, could fail to properly attend to the driving task.

2.1.2.4 Fail Safe Design

Comment 1:

Not clear what this section means. Explain.

Comment 2:

A key point is that driver attention should be directed to the crash hazard, not the CAS.

Comment 3:

Delete, "Malfunctioning systems should be automatically placed in a failure mode."

2.1.3 Parameter Initialization

Comment 1:

Current driver is initially informed of non-default settings or is provided with adequate default settings. The default settings should be displayed to the driver on command.

2.2 Levels of Warning

Comment 1:

I have encountered numerous individuals who only refer to "false alarms" with regard to collision warning systems, without distinguishing between alarms triggered by appropriate and inappropriate events. This distinction must be considered in discussing the false alarms issue, and I am pleased to see the manner with which it is addressed in this report.

Comment 2:

Consider adding that cautionary warnings can provide more information about the situation and be less prescriptive since there is presumably more time to react.

Comment 3:

Intrusive and urgent signals may also, unfortunately, be startling and therefore disruptive. Perhaps warning signal designs should be assessed for both classes of effects. Also, no provision or example is provided on how to achieve "more urgent" and "more intrusive" signals.

Comment 4:

Imminent crash avoidance warnings use a more urgent and intrusive signal, while cautionary warnings provide the driver with greater advanced warning in a less disturbing form. Research is required to determine how urgent and intrusive a signal can be and not itself pose a safety hazard; and how advanced warnings are displayed.

Comment 5:

Maybe the distinction should be made here between levels of warning and graded warnings (discussed later, e.g., page 2-18).

2.2.1 Definition of Imminent Crash Avoidance Situation

Comment 1:

This will differ greatly by driver type.

Comment 2:

Features: a) It appears that "visual" and "auditory" have been transposed. b) Tactile warnings have a broader research base than suggested by the draft. c) Visual displays may prompt the driver to take eyes off the road scene at crucial times. (Point "c" is critical and must be verified in studies or evaluations.)

Comment 4:

An imminent crash avoidance situation is defined as one in which "...the potential for a collision is such that it requires an immediate vehicle control response or modification of a planned response in order to avoid a collision." Unfortunately, this definition does not address the fact that some imminent crash avoidance scenarios may not appear to require an immediate vehicle control response. For example, a driver might tailgate another vehicle and be in absolutely no danger of colliding with that lead vehicle, so long as the lead vehicle does not brake suddenly. If we assume, however, that the lead vehicle could brake suddenly, than the scenario does require an immediate vehicle control response.

Comment 5:

Time aspect? How immediate is immediate? Provide quantitative guidelines as much as possible.

Comment 6:
Why "acoustic" rather than "auditory"?

Comment 7:
Features - On prioritization coding...It should be acknowledged that the significance of various signals may a) never be learned in the first place, or b) may be forgotten.

<u>2.2.2 Definition of Cautionary Crash Avoidance Situation</u>

Comment 1:
This section does not define anything concrete.

Comment 2:
Implies that critical warnings should be both auditory and visual while cautionary warnings should be only visual. In an environment of numerous cautionary warnings, a cue must be provided when a new warning is present.

Comment 3:
So should imminent collision alarms.

Comment 4:
The kinematics of the pre-crash situation may be such that there is not enough time for cautions or the time difference between the caution and warning signals may be small. Abraham Horowitz (TRB, 1994) has put forward a concern that there may a psychological refractory period (PRP) effect that would actually slow driver response. To this, I would add the possibility of masking effects between first and second signals when they are presented close in time.

<u>2.3.1 System Query</u>

Comment 1:
Should be titled "Automatic Presentation" rather than "System Query". The requirement for warnings that are automatic should be stressed. A query-based warning system is antithetical to the nature of warnings -- by definition warnings elicit attention.

<u>2.3.2 Prioritization of Multiple Warnings</u>

Comment 1:
"Systems with simple algorithms", why distinction?

Comment 2:

Min. standards stated; fancier modes may augment but not violate min. standards.

Comment 3:

What about multiple systems which use visual caution and auditory imminent warnings (same tone)? This could be ambiguous in a simultaneous alert situation. What about an 'open architecture' to allow for add on devices to the original 'system' or evolving vehicle designs over time? The discussion of "... systems which have more intelligent capabilities..." lists a number of possible input factors but makes no attempt to suggest how warnings should be prioritized.

Comment 4:

Please clarify the nature of a non-target specific imminent crash avoidance situation.

Comment 5:

"Such factors include, but are not limited to, severity of potential collisions, appropriate responses, temporal proximity, driver response time and distance, consequence probability, message redundancy, perceptual difficulty, warning validity, causal relationships, and informativeness of the warning." Some of these (above) need examples for non-HF readers, e.g., perceptual difficulty.

Comment 6:

On p. 2-9, para 1: Consider the human performance value (liability issues aside) of a warning that indicates the required crash avoidance maneuver (e.g., possibly reduced reaction time delay and increased accuracy of driver response).

<u>2.3.3 Rules for Display of Multiple Warnings</u>

Comment 1:

"b. Only the highest priority warning in effect should be presented by means of an acoustic or tactile display" - How is this alert distinguished as unique in the case of multiple simultaneous warnings?

Comment 2:

b. add "or both" after display.

Comment 3:

This is a complex area. I believe more work may be needed. Perhaps multiple warning situations and likely task sequences should be hypothesized and studied (e.g., car ahead stops short as crossing vehicle illegally enters intersection ahead). Is this being done? As far as the signals themselves are concerned, one approach is to use standard warning signals for the existence of warning or cautionary conditions. The specifics of the situation can be conveyed via a supplementary signal. For example, if voice is used the warning could be: "Warning!" followed by specifics, "intersection intrusion". I think this section needs work and probably more research. Time required for conveying the information and the possibility of false alarms (if signal has to start early) must be considered.

Comment 4:

c. "a clearly distinguishable cue" The guidelines should define what criteria make a cue clearly distinguishable.

Comment 5:

One of these rules states that all crash avoidance warnings should be presented simultaneously via visual displays. However, the authors do not provide any guidelines for presenting the displays in a fashion that will minimize visual clutter and excessive cognitive workload. One can imagine a situation where there are four different warning displays being illuminated at the same time and the driver must attend to all of them -- it would not be surprising if the driver begins to ignore some of the displays over time. Prioritization of non-imminent crash warnings should also be considered.

Comment 6:

Not consistent with 2.2.2.

Comment 7:

c. major problem here.

2.3.4 Automatic Termination of Warnings

Comment 1:

Discussion re: this - reset can be effected after hazard past.

2.3.5 Compatibility of Warning to Driver Response

Comment 1:

"... For example, a vibrotactile signal from the accelerator pedal may cause drivers to look down at the pedal..." - The traction control system on late model Corvettes uses this mode of 'display' and it works quite well.

Comment 2:

Item b, pg. 2-11: The guideline as stated will often be impossible since a direct tradeoff will exist between target detection capability and false alarms.

Comment 3:

As stated under 1.4 above, the guidelines should state early in the document exactly how the driver is expected to respond given alternative situations triggering activation of each device.

Comment 4:

The accelerator pedal example has been assessed in the European DRIVE program and shows promise (see the book by John Michon (1993), GIDS: Generic Intelligent Driver Support.

2.3.6 Prevention of False/Nuisance Warnings

Comment 1:

I agree with the approaches described for reducing false alarms. Of course, these need to be applied after considering the nature of the alarm and the associated situation, and in the context of the entire warning system (as stated in the detailed text). The definitions of false and nuisance warnings need to be improved. Perhaps false alarms could be defined as those for which the actual situation does not warrant an alarm, and nuisance alarms as those false alarms that occur frequently causing annoyance. This should be discussed (perhaps at the workshop) and more complete definitions agreed to.

Comment 2:

Allowing the driver to reduce detection sensitivity to a restricted limit is risky. For one thing, it assumes that drivers will be competent to understand and control sensor sensitivity. Secondly, the impact of driver-induced modifications to sensors on driver safety needs to be assessed.

Comment 3:

Point b: The driver cannot reduce detection sensitivity to minimize false/nuisance alarms without significantly affecting the target detection capability of the device. The tradeoff between correct detections and false alarms is fundamental in signal detection.

Comment 4:

Point c: Given that pre-crash conditions may be severely time-limited, the specified minimum amount of time criterion may not be feasible.

Comment 5:

Point d: To reduce warning intensity or volume reduces intrusiveness. To reduce intrusiveness is to reduce conspicuity for the inattentive driver. Driver inattention is a key contributor to crashes.

Comment 6:

The tolerance level for crash avoidance warning systems probably varies by circumstances and by person. For example, a driver may be more willing to accept false alarms from a drowsy driver detection system between 2am and 4am than between 8am and 10am.

Comment 7:

In the last paragraph of this section, the first sentence reads, "It is suggested that by requiring the sensed object or hazardous situation to be persistently detected for some minimum period of time, false/nuisance warnings can be reduced." I believe that this "fix" will lead to a reduction in the number of false alarms, but not necessarily the number of nuisance alarms. This belief is based on the fundamental definition of "nuisance alarm" provided in the report.

Comment 8:

b. How, why? "B" level should be optimized. d. reset?

Comment 9:

The authors recommend that the driver be allowed to reduce the system's detection sensitivity to a restricted limit that minimizes false/nuisance alarms without significantly affecting the target detection capability of the device. I maintain that <u>any</u> reduction in system detection sensitivity will affect the target detection capability of the device, and we need to make sure that drivers understand this preference/performance tradeoff. This may be more easily said than done.

<u>2.4.1 Characteristics of Auditory Imminent Crash Avoidance Warnings</u>

Comment 1:

"... imminent crash avoidance warnings should be consistent across 'crash avoidance devices'..." - Does this mean the same type of device should be consistent from car to car or the same type of warning should be consistent across devices within a single car?

Comment 2:

In the context of a headway warning system, we found no significant difference in the timing of drivers braking responses for a speech display compared to a non-speech display (Hirst & Graham, 1994). However, subjects clearly preferred the non-speech warning, finding speech output irritating (although this may have been due to the repetitive nature of the experiment). We would recommend non-speech warnings for a system dedicated to a particular type of hazard (eg. a pure headway warning system), but speech for an integrated collision avoidance system, due to its increased informational content.

Comment 3:

Not consistent with 2.2.1

Comment 4:

"be distinctive" in second sentence, how is this measured? Address relative vs. absolute comparisons in defining distinct.

2.4.2 Characteristics of Auditory Cautionary Crash Avoidance Warnings

Comment 1:

"... In addition, auditory warnings may not be perceived in noisy driving environments..." - But you just recommended auditory displays for imminent alerts?!

Comment 2:

It should be noted that auditory warnings will not work with deaf drivers (and there are some). Also in the last line...It is not possible to state that visual cautionary warnings are preferred due to the visual workload imposed right when the driver should be attending to the driving scene.

Comment 3:

Not consistent with 2.2.2.

2.4.4.1 Cuing for Directional Hazards

Comment 1:

Devices which provide auditory warning directional information should locate the sound source such that the warning appears to emanate from the position in the vehicle which is closest to the location of the target or crash situation which triggered the warning. This assumes that the driver will always need to know from where the threat is occurring. This is a research issue: having knowledge of the directionality of the threat vs interference of the directional signal on the ongoing driving task.

Comment 2:

This guideline states, "Devices which provide auditory warning directional information should locate the sound source such that the warning appears to emanate from the position in the vehicle which is closest to the location of the target or crash situation which triggered the warning." With three-dimensional auditory display technology, I believe it will be possible to make a warning appear to come from the location of the external hazard itself. The question then arises of whether the warning sound would be better presented from an apparent point inside the vehicle or one outside the vehicle.

Comment 3:

There's newer research being done by Rich McKenley (Armstrong Lab, Wright-Patterson AFB).

2.4.5 Characteristics of Acoustic Displays

Comment 1:

This entire area would be much improved through reference to more recent research in the area. Although I am not familiar with this area of research I know the Roy Patterson, Applied Research Unit, U.K., and others have conducted research in this area for application such as aviation, hospitals, public facilities, etc. I believe a lot of this research is relevant and more up-to-date than the guidelines provided in this section.

2.4.5.1 Coding of Levels of Warning

Comment 1:

Table gives impression of being inconsistent with the text - duration coding is not recommended - intensity coding is not recommended - yet they appear in the table as if they are the recommended approach - need to clarify.

Comment 2:

Please clarify the meaning of "large/small frequency oscillations within auditory patterns."

Comment 3:

Give numbers! What frequencies are high/low?

2.4.5.2 Fundamental Frequencies

Comment 1:

Some information on the noise environment of cars and trucks would be helpful to interpret this guideline.

2.4.5.4 Default Warning Intensity

Comment 1:

If the driver has a high-performance sound system turned up to 90 dB (not implausible, especially for younger drivers), then the warning intensity must be up to 120 dB. This violates OSHA regulations for peak noise exposure.

2.4.5.6 Warning Duration

Comment 1:

For repetitive tone presentation.

2.4.5.7 Warning Repetition

Comment 1:

50/50 on/off cycle (1472D)

Comment 2:

There is no guideline which states what a minimum warning duration should be. For example, in my recent study of collision warning system displays, I required all warning displays to be activated for at least one second. If there is no minimum warning duration, the driver may hear, see, or feel a momentary warning which might seem foreign to her or him. Please note that this comment holds true for all types of warnings (i.e., visual, acoustic, tactile, and speech).

2.4.6 Characteristics of Speech Displays
Comment 1:
How meet?

2.4.6.3 Message Content
Comment 1:
Speech displays might indicate imminent and cautionary conditions in the way a passenger would receive them, i.e., by means of volume, pitch, and inflection. An example: " Vehicle Ahead" (crash-possible caution in normal voice, normal volume: " Stop." (crash-probable warning in louder, more urgent tone). " STOP!!!" (crash-imminent warning in even louder, strident tone).

2.4.6.4 Message Presentation
Comment 1:
Given the dramatic improvements in synthetic speech in the last two years, a more recent reference would be better.

2.4.6.7 Voice Characteristics
Comment 1:
Compare with 2.4.6, why repetition?

Comment 2:
Quantify the frequency bands that should be used.

2.4.6.10 Use of an Alerting Tone Preceding Speech Messages
Comment 1:
This all talks as though the audio signal is only display, but both modes are presented for collision avoidance.

2.4.7 Control of Auditory Display Intensity
Comment 1:
2.4.6.9, why 2 comments?

2.4.7.1 Automatic, Adaptive Control of Auditory Display Intensity
Comment 1:
c.f. 2.1.1.1

2.4.7.3.1 Minimum Intensity
Comment 1:
If minimum intensity is still clearly audible, the motivated driver will turn the

device off, leaving no protection at all.

Comment 2:

Real danger here - set @ min. and forget it.

2.4.7.3.3 Master Intensity Control

Comment 1:

Giving the driver a master intensity control and individual adjustments for each system is simply too many knobs.

2.5 Visual Displays

Comment 1:

Consistency with previous?

2.5.1.1 Simplicity

Comment 1:

The first sentence in the explanation includes a fundamental contradiction - "The major function of primary visual displays is to capture the driver's attention and to direct the driver's attention to the hazard". This conflict must be adequately researched and cannot summarily be disposed of by requiring primary displays to be simple.

2.5.1.1.2 Location

Comment 1:

How is the "driver's expected line of sight in a given crash avoidance warning situation" to be determined? Is this something that changes continuously during the drive, requiring some fancy adaptive re-location of displays? Can this recommendation be applied to vehicles?

2.5.1.1.3 Manual Adjustment

Comment 1:

This and similar paragraphs require the use of controls to adjust display parameters. The use of automatic intensity controls should be used to avoid the driver having to make manual adjustments. The number of driver controls must be kept to an absolute minimum to avoid problems similar to operating a modern automobile radio.

2.5.1.2 Secondary Visual Displays

Comment 1:

Under this section, the topics of usable information, legibility, and icons/pictographs are discussed. I am curious as to why these topics were not also mentioned with regard to primary visual displays.

2.5.1.2.2 Display Legibility

Comment 1:

Display characters should suspend a minimum visual angle of at least 12 minutes of arc. The age and eyesight of the driver also needs to be considered. We suggest consideration of a larger minimum visual angle than 12 arcmin. A character of that size would only be just resolvable to a person with 20/48 acuity. There are three reasons for thinking that such a character size might prove unresolvable to many licensed drivers: First, acuity measurement is inherently variable so that an individual with 20/50 acuity might pass the test at the 20/40 line, become licensed, but be unable to resolve the 20/48 character. Next, acuity can decline markedly under night illumination conditions but the licensure test is not conducted under those conditions. Finally, many states allow licenses by exception so that acuity considerably worse than 20/40 can be allowed.

Comment 2:

How will an engineer get these data? Give criteria - font size, stroke width, etc. There's a MIL-SPEC on this.

2.5.1.2.3 Icons / Pictographs

Comment 1:

This is an obvious standards opportunity.

Comment 2:

Icons should be standardized. Applicable icons should be adapted from existing domestic or international icons.

2.5.2 Characteristics of Visual Imminent Crash Avoidance Warnings

Comment 1:

We agree with the utility of flashing displays in contrast to steadily illuminated alternatives. This well established principle in the human factors field is readily understood by reference to the human temporal contrast sensitivity function which exhibits bandpass properties where peak sensitivity is around 5-6 Hz. It is an example of a more general strategy of matching the frequency content of stimuli to the multidimensional spatio/temporal contrast sensitivity function. (That other examples of this more general strategy have not received attention in the literature is due to many factors, not the least of which is the ease with which lights can be made to flash and the relative difficulty, at least until recently, of doing anything more exotic.) However, in our view, the range of possible spatio/temporal variation that could be employed to take advantage of higher intrinsic visual sensitivity for certain visual stimuli has not been fully explored, and is not fully covered by flashing. At least one example may be found in Boff and Lincoln, 1982. Our project has as one of its aims the test of a display that employs a different version of this more general strategy and initial results suggest visibility and conspicuity improvement beyond that achievable with flashing. We thus suggest the revised wording of the first sentence for this item as follows: An imminent crash avoidance warning should be presented by means of a prominent, **red indicator(s) some or all of which is rapidly flashing,** and should meet all criteria for primary visual displays (Section 2.5.1.1). Imminent...display. (third sentence) Because... (MIL-STD-1472D) in comparison to steadily illuminated displays, red flashing...

2.5.2.1 Flash Rate

Comment 1:

Imminent crash avoidance warnings should have temporal characteristics matched to the filter characteristics of the eye. For example, flashed warnings should have a flash rate of five flashes per second with equal on and off times. This suggested change leaves room for other temporal variation, beyond flashing, provided that it confers additional visibility or conspicuity.

Comment 2:

With a flash rate as high as 5 Hz (50 percent duty cycle), I doubt that all drivers will be able to identify any text or symbols which might be displayed. Perhaps a red flashing box should appear around the text or symbol of interest, with the text or symbol being continuously illuminated.

2.5.2.2 Flash Synchrony

Comment 1:

We recommend reconsideration of the suggestion for synchrony. We know of no evidence that confusion or disturbance can result from asynchronous flashes. To the contrary, one might worry that two signals simultaneously flashed might fail to alert the observer that two events are being signaled. Unless compelling evidence exists demonstrating confusion or disturbance, and until experimental evidence can be found to refute the possibility that two- warnings will merge into one, we recommend suspension of this item.

Comment 2:

So what? If primary warning device, should be disturbing. Can't do this and meet 2.5.2.

2.5.2.3 Visual Display Deactivation

Comment 1:

If no display, doesn't make any difference if system is display off vs. entire system off.

2.5.3 Characteristics of Visual Cautionary Crash Avoidance Warnings

Comment 1:

This guideline assumes foveal vision. It is important to note that color coding will not necessarily work when drivers are not looking directly at the display. Humans are color blind in the visual periphery.

Comment 2:

I am concerned that a continuous red cautionary warning might be easily confused with other continuous red warnings which appear on the instrument panel (e.g., brake, seatbelt). Additionally, I cannot help but wonder whether all drivers will correctly recognize the distinction between a continuous and flashing display.

Comment 3:

So flash red, steady red, steady yellow.

Comment 4:

What about blue for status information?

2.5.3.1 Display by Exception

Comment 1:

If no target or critical situation is sensed by the crash avoidance sensor system, there should be no display to the driver **confusable with, or that might mask, a warning signal.** We urge further thought on this item for three reasons: 1) A color change can be more visible than a light turned on. If a warning signal is a unique shape at some place in the field (e.g. a star), putting a green "safe" star there that turns red to warn, would be more visible than a red star that turned on at the right time (Chaparro, et al, 1993). Of course a red-green color defective observer would not benefit but would be disadvantaged. We should consider the possibility that future displays can be tailored to the needs of the observer (so an observer with red-green confusion might be given a display that only turns on). 2) A cue to accommodation lowers search time: This finding argues for a continuously illuminated design in the display field, though not where a warning signal can arise. Such a design serves as a cue to accommodation. 3) A coordinate system abets the aims of Section 2.3.5. A steady cue that serves also as a coordinate system within which a given warning achieves additional salience by virtue of its coordinate position (e.g. a warning to the right of center relates to a collision situation on the right.)

Comment 2:

If the above reasoning is viewed as acceptable, then the comment for this item might be altered by adding a pair of lead sentences and then by modifying the last sentence: **The designer may employ a continuously on "reference" signal provided it not be confusable with any of the possible warning signals either in shape, position or color.** "Some current ...warning." **Signals presented in the absence of a need for a hazard signal should be designed to not exacerbate** driver overload and confusion.

2.5.3.2 Size

Comment 1:

A size specification is problematic and insufficiently general to allow further advances. The COMSIS guidelines treat an indicator light as a simple shape (probably circular) with a single size parameter (presumably diameter). Indicator lights could easily have a different geometry and some of the very earliest reliable psychophysical data demonstrated a preference, in terms of threshold, for narrow slits over more symmetrical figures (cf. Boff and Lincoln, 1988 for summary). The next issue has to do with how big. The guidelines point to a minimum angle of 1 degree. However, the research on which that figure is based (Sheehan, 1972) relates to recognition of character-based messages. Other research, cited in the referenced Aircraft Alerting Systems documents, deals with simple shapes. Except for the visual periphery under dark adapted conditions, the best size for simple shape detection is considerably less than one degree. (In the periphery the figure might be as high as 0.5 DEG in the dark). In the fovea for example, spatial summation is easily complete beyond 5 arcmin diameter and so no advantage would be accrued from making the indicator bigger. However, a bigger indicator does supply increased pressure on the construction of the rest of the display, which needs to be compact.

Comment 1:

Finally, there is the issue of spatio/temporal variation designed to match human visibility characteristics. Just as a flashing light is better than a steady light and a striped indicator better than a plain one, so too a combined spatio/temporal variation may be even better yet. Results from Watson, et al, 1983) support this view. Only research will tell whether the promise of this line of thinking can be realized in an actual display. However, in the meantime, one needs to supply guidance that does not restrain improvements. The guidelines should be written with enough flexibility to embrace any advances that benefit visibility and conspicuity. Recommended wording: **Size, position and shape of discrete component based indicator lights should be chosen to optimize visibility and conspicuity. For symmetrical discrete shapes this means a maximum of about** 0.5 DEG. **Other modes of display (e.g. CRT, HUD) should provide an equivalent level of conspicuity (TBF).** We recommend a deletion of the first sentence and the word "however" that begins the second.

Comment 3:

Depends on where located in field.

2.5.4 Characteristics of Status Indicator

Comment 1:

Need to clarify order of statements. This appears at first to contradict section

2.5.3.1 on display by exception. Not clear until half a page later.

2.5.4.1 Power Indication
Comment 1:
Basis of assumption?

2.5.4.2 Color
Comment 1:
c.f. 2.5.3, assumes a different status indicator than warning indicator - OK 2.5.4.4

2.5.4.4 Location
Comment 1:
This item should provide guidance on display integration, involving combined and prioritized parameters.

2.6 Tactile Displays
Comment 1:
General comment: See Michon (1993) for a report on recent work in the DRIVE program on tactile displays. They appear to hold promise for CAS design.

2.6.1 Compatibility of Warning to Driver Response

Comment 1:
It should be noted that there may not be an effective display for the drowsy driver. This remains to be demonstrated. Therefore, this should not be a criterion for judging the viability of tactile displays.

2.6.2.1 Frequency
Comment 1:
Vibrational frequencies of 3.5 - 4.5 Hz (as opposed to 3 Hz) should be avoided for the driver's seat (Sanders and McCormick, 1987), but I do not think that these frequencies would present a nausea/discomfort problem if presented via the accelerator pedal or the steering wheel. These are the resonating frequencies for the seated body, but the resonating frequencies for the arms and the legs are going to be different.

2.6.2.3 Duration
Comment 1:
Should be general cycle for all types of displays.

2.7.1 Master Intensity Control
Comment 1:
This section seems redundant - information is already in previous sections.

Comment 2:

The guideline states that at the lowest setting, the display should be perceptible for all anticipated driving conditions. Who is the target driver in these driving conditions? Is it a young, alert male or an older, inattentive driver? The assumptions about the target driver will significantly influence the control design.

2.7.2.3.4 Size and Texture Coding

Comment 1:

It is not clear that these guidelines, developed for military equipment, are applicable to modern automobiles. I do not know of better standards but that does not necessarily validate MIL-STD-1472.

2.7.2.4 Texture

Comment 1:

Note that finely serrated knobs must nonetheless be discriminable by the driver wearing gloves.

2.8 User Documentation

Comment 1:

f. "based on word difficulty", quantify this.

3.0 Blind Spot Warning Devices

3.1 Blind Spot Warning Device Application

Comment 1:

Deactivating the device at a very low speed (i.e., 5 miles per hour) provides another means for further eliminating inappropriate warnings. It may be that in a lane merge situation, where a driver is entering a limited access high speed roadway, that such a warning would be most beneficial. In this case it would have to be operative at low speeds since the merging driver may be proceeding from a full stop.

3.2 Device Activation

Comment 1:

Deactivating at low speeds may eliminate some important warnings for the driver. Commercial drivers, operating in urban driving conditions often complain of situations where passenger cars attempt to squeeze between their vehicle and the curb to make a right turn and as a result get caught in a "pinch" accident. These accidents almost always occur at low speeds when a deactivated sensor would leave the driver without assistance in detecting this type of frequent accident.

Comment 2:

I believe that future research will show that these systems will be acceptable only if activated by turn signal use. At the very least, this is a possibility that should be acknowledged. Perhaps turn signals can be modified to have a "two-click" operation - one click to the left for a lane change to the left (activating the blind spot sensor) and two clicks to the left for a left turn (no sensor). This will, in a sense, be an exception to the "system query" guidelines stated in 2.3.1. .... Later, in 3.4.1, you allow for the possibility of system activation for Imminent warnings by turn signal use. Is this a contradiction?

Comment 3:

"It is permissible...", may be mandatory.

3.3 Primary Visual Display Location

Comment 1:

Eliminate "and pending research, the optimal visual display location will be determined."

3.4 Levels of Warnings

Comment 1:

It makes sense to have pre-maneuver and during-maneuver levels of the warning. However, once the maneuver has begun the full intensity warning should be provided since the lateral distance between the vehicles is so small.

Comment 1:

Last sentence of rationale. Questionable let's find out before doubting info input.

3.4.1 Imminent Crash Avoidance Warnings

Comment 1:

a) Need a predictor of driver intent (e.g. turn signal) - action is too late at these distances (e.g. motion). b) Eighteen inches seems like an extremely small distance. c) Don't worry about where the lane marker is - worry about vehicle lateral path spacing - crashes can occur anywhere on the road.

Comment 2:

(The device) only addresses cases where the driver signals his or her intent to change lanes. It is implied that some other means of device activation is needed for cases where the driver does not signal. A case can be made for protecting the driver who follows correct procedure, and not providing special (and potentially costly) support for the driver who does not follow correct procedures. A need also exists to address the situation where, in congested traffic, a driver may signal to move into another lane, intending that the signal causes an oncoming driver in the lane to back off, allowing the lane change. In this situation, where several lane changes may occur, repeated activation of the imminent warning may be distracting and annoying.

Comment 3:

I believe that most lanes are 12' wide, with some as narrow as 10'. Most vehicles are about 6' wide. Thus, the mean lateral distance between vehicles is about 6'. Lateral distances of less than 18" are certainly too close, but I wonder if it should be 24" or 30".

Comment 4:

"...given that the driver uses the turn indictor." A questionable assumption.

Comment 5:

"This latter limitation is of particular concern, given the probable abrupt nature of lane changes suggested by police reports." How abrupt? Quantify, provide user with data.

<u>3.4.2 Cautionary Crash Avoidance Warnings</u>

Comment 1:

Again, serious T/O here.

Comment 2:

A cautionary crash avoidance situation is one in which there is an object in the detection zone (blind spot) but the object is not within the immediate or intended pathway of the vehicle. This criterion is not clear, unless it is saying that a cautionary crash avoidance warning is presented whenever an object is in a position which, on a lane change, could pose a hazard.

Comment 3:

Would not an "at request" blind spot detector be useful? Or would people use it instead of looking back? If they did, would it matter?

<u>3.5 Detection Zone</u>

Comment 1:

a) This is a performance specification, not a human factors guideline. b) What about a motorcycle between a car and a truck (large targets, strong masking signal)? c) Need to define blind spot in a measurable fashion.

<u>3.5.1 Area of Coverage</u>

Comment 1:

Limiting the field of detection to 10 feet laterally cannot capture targets in "all likely lane positions."

Comment 2:

Perhaps you should soften the prohibition against "holes," since a system without holes may be difficult to achieve for long vehicles (i.e., trucks). Maybe you should specify that no holes could permit a small sedan or motorcycle to go undetected.

Comment 3:

The maximum 12' lateral distance may be too high - it could extend into the second lane, and especially would be a problem as drivers complete their lane change maneuver. Most likely, the system needs to turn itself off or reduce its coverage area as the lane change maneuver is completed to prevent being activated by a vehicle in the second lane to the right (or left-to-right lane changes).

3.5.2 Location of Detection Zone

Comment 1:

I think we should decide and state it.

3.5.2.1 Light/Passenger Vehicles

Comment 1:

Priority designation for left-side blind spot area is not strongly justified. In 1991, there were almost as many right side impacts for lane changing/merging passenger vehicles (38.9 percent) as left side impacts (42.5 percent). I don't recall the data you cite as "Knipling, 1992" but I feel that the newer data is more definitive.

3.5.2.2 Heavy/Commercial Vehicles

Comment 1:

Great!

3.6.1.1 In Light/Passenger Vehicles

Comment 1:

Explain.

3.6.1.2 In Heavy/Commercial Vehicles

Comment 1:

Explain.

3.6.2 Auditory Warning Displays

Comment 1:

Auditory warning displays may be used to indicate the direction of the hazard. Not required if the activation of the turn signal triggers the imminent warning sensor.

3.6.3 Tactile Warning Displays

Comment 1:

COMSIS report recommends that "tactile directional indicators...should not be used for cautionary crash avoidance situations". I think that the evidence from the quoted studies is not sufficient. The area of tactile warnings, and furthermore the fascinating area of the role of a semi-automatic system to provide indirect warnings, is in its infancy.

Comment 2:

"Tactile warning displays may ..." is not consistent with last part of rationale, "should be thoroughly tested prior to their implementation in warning devices."

3.7.2.2 Auditory and Tactile Warning Displays

Comment 1:

How do you implement "... Transient manual override controls..."? Could you use the turn signal to arm but not activate the imminent warning? We are defining the performance specification again.

Comment 2:

The use of transient manual override controls is simply not compatible with the normal driving task. The requirement for a positive driver action to prevent nuisance alarms is, in my view, not acceptable. The number and frequency of relevant maneuvers is high and the probability of forgetting/forgoing the override is also high.

Comment 3:

The "two click" directional signal concept described above would preclude much of this problem and would be easier to use than the device described for turns at intersections.

Comment 4:

Disagree with lane turn, override extra position on directional signal. (last paragraph of section) The process is too complicated. Something else, or nothing is needed.

Comment 5:

Tricky and potential show-stopper. Logic probably has to be smart enough to detect stationary objects and opposing traffic.

3.8 Detector Sensitivity Adjustment

Comment 1:

"A control may be provided to allow the driver to adjust the range of the sensor field to reduce sensitivity and false alarm rates." NO - what criterion would the typical driver use to calibrate his / her adjustment to real world crash risk?

Comment 2:

A control may be provided to the driver to adjust the range of the sensor field so as to reduce false alarm rates. However, instructions and another indicator should make the driver aware that in doing so the rate of detecting real hazards will also decline. Controls/adjustments should meet all requirements for controls/adjustments in Section 2.7.

Comment 3:

We have a terminology question here. In the signal detection literature, sensitivity is a quality of the detection process. The more there is the higher the hit rate at a given false alarm rate. Criterion cutoff is what one would adjust to lower false alarm rate. This would also lower hits or detections, the average rate of which is termed sensitivity, in the epidemiology literature. Sensitivity in the engineering literature refers to a system gain, for example the amount of transducer signal required for a volt of indicator output. Since the guidelines could be as easily read by someone from any of the three aforementioned disciplines, and since the message changes markedly depending on the meaning one attaches to a given term, some attention might profitably be paid to rendering the text, whose message is quite appropriate, less ambiguous. Our suggestion rests on the bedrock idea of false alarms and a control to reduce them.

4.0 Backup Warning Devices

Comment 1:

Definition of imminent crash avoidance situation: Features - imminent crash avoidance warning should <u>not</u> provide <u>any</u> visual display. Warning should be in the form of a staged auditory warning that provides warning of a target in the path of travel that changes to a different tone as the target reaches the point of 48 inches at which point the tone will "geiger" in frequency up to the point of a steady tone which indicates less than a foot to impact. Drivers' will use varying rear view mirrors depending on the vehicle and situation which nullifies the attempt to locate a visual display in some specific location.

<u>4.1 Device Application</u>

Comment 1:

Middle paragraph (Pg. 4-1).....more intelligent sensor systems (and more complex user interfaces) than are currently available...

Comment 2:

Disagree. Why write standard to present SOA. It's bound to change and need <u>guidance</u> as it comes alive!

Comment 3:

"do not apply to devices intended to function solely as parking aids." May apply?

4.3 Backup Warning Device Primary Visual Display Location

Comment 1:

There is an implication that a display located on the rear window could be read either by a driver looking backward or through the rear view mirror. The problem here is one of mirror imaging. A display meant to be read through the mirror can't be read directly.

4.4 Backup Warning Device Levels of Warning

Comment 1:

The scenario presented to substantiate the need for a gradient warning device seems to be contrived (child sitting in the road closer than a parked vehicle) and highly improbable. Certainly it would not be cost effective to require the additional (and probably relatively high) cost of a gradient sensing device for such a situation.

4.4.1 Imminent Crash Avoidance Warnings

Comment 1:

2nd paragraph. Could not the warning-zone range be made to reflect vehicle speed also? Are guidelines needed here?

Comment 2:

(Pg. 4-4) top....the 95th percentile (hard-braking) stopping time.... The hard braking distribution (e.g., after a warning) would be very different from the normal braking distribution.

Comment 3:

Will need to get backing RT under the same ops condition.

4.4.2 Cautionary Crash Avoidance Warning - Backing Maneuvers

Comment 1:

Should have a short "caution" auditory signal at the onset, and then a remaining visual signal as long as the situation occurs. Don't try to have the CAS system evaluate degree of caution. It places too much responsibility on the system and little on the driver.

4.5.1 Rear Zone Coverage Area

Comment 1:

Detecting objects "already adjacent to the real bumper....as well as objects near the ground which are immediately below the edge of the bumper" is certainly a worthy goal but like the statement that there should be no "holes" in the detection area of the sensor is overly idealistic and must be considered against the cost benefit.

Comment 2:

Last paragraph - What is the point?

Comment 3:

"Backing speeds are typically 5 mph or less." Reference?

4.6.2 In Heavy/Commercial Vehicles

Comment 1:

Questionable - truck driver isn't that much dif. from car driver - overload information.

4.7.1.1 Imminent Crash Avoidance Warning Displays

Comment 1:

What about getting out of R.

4.7.2.2 Auditory and Tactile Warning Displays

Comment 1:

No. don't do this for backing alarms - you don't spend that much time backing.

5.0 DRIVER ALERTNESS MONITORING DEVICES

5.1 Device Application

Comment 1:

Equating fatigue, sleep deprivation, drug abuse, medication, etc. assumes that all involve equally rational driver reactions subsequent to the warning. This seems unlikely. Also, drowsiness is dangerous in itself, not just sleep onset.

Comment 2:

But it will be used that way. Must accommodate in design. Also, must be careful not to let SDA drive standard.

Comment 3:

(Pg. 5-1) Do you need to cite data on target crash incidence? All of your citations here are problematic: ! Citation of NTSB study is misleading/incorrect. That study dealt only with single vehicle fatal-to-the-driver heavy truck crashes, a very different population than "fatal-to-the-driver accidents."

! Same paragraph: 40 percent estimate from AAA Foundation for Traffic Safety seems very high; not corroborated by other studies.

! Same paragraph: need to change citation from NHTSA OCAR re: 135,000 crashes. That value is a couple of years old and includes non-police-reported crashes (an estimate). If you absolutely need numbers to cite, we'll run some 1992 numbers on police-reported crashes for you.

5.2.1 Alertness Sensing Methods

Comment 1:

Call out must survive rationale. This sentence too cryptic. "Remote or proximal sensing...."

5.2.2.1 Remote Sensing Devices

Comment 1:

Giving the driver the opportunity to turn the device off when it is inappropriate to measure drowsiness assumes the driver can rationally make that judgement. Yet the preceding material indicates that the driver is often unaware of sleep onset.

Comment 2:

Add to guideline "However system should activate regardless of last state when engine turned off or vehicle placed in Neutral or Park.

Comment 3:

Last sent. of rationale - tricky what harm if on and driver just on short trip?

5.2.2.2 Proximal Sensing Devices

Comment 1:

Instead of the phrase "forward gear", simply use "gear". This will cover all vehicle-in-motion conditions (e.g., backing).

5.2.4 Device Fitting/Mounting Interface

Comment 1:

May be useful in CVO applications, however.

5.3.1 Auditory Sound Source Location

Comment 1:

Again, it should be noted that an arousing auditory (or other) signal may be startling to be effective.

Comment 2:

Headset is illegal in some states.

5.3.2 Visual Warning Display Location

Comment 1:

Visual warnings seem inappropriate given that drowsiness is indicated by eyelid closure (among other things).

5.3.3 Tactile Warning Display Location

Comment 1:

Please include the reference that demonstrates tactile displays are startling to the drowsy driver. Also, the locations for tactile warnings are constrained to the steering wheel, pedals, floorboard beneath the driver, and the driver's seat (not including worn items).

5.4 Levels of Warnings

Comment 1:

The notion of sleep inertia is an important one. It may ultimately determine the success of drowsy driver warning systems.

Comment 2:

Reference should also be made of the work of Walter Wierwille at VPI&SU on drowsy driver detection.

5.4.1 Imminent Crash Avoidance Warnings

Comment 1:

It is my opinion that drowsiness is always an imminent crash hazard, if only because of a lane departure threat. The distinction between cautions and warnings may be inappropriate here. For example, if the driver is asleep it is too late for crash avoidance. Thus, all drowsy driver warnings should indicate dangerous conditions.

Comment 1:

"The warning should be rapidly and reliably detected by a drowsy driver." Probably rules out any visual display except for deaf driver.

5.4.1.1 Warning Ambiguity

Comment 1:

If the drowsy driver is going into a particular crash hazard (e.g., roadway departure), perhaps the warning should be integrated with the crash-specific warning display (e.g., indication to steer in the required direction).

5.4.1.2 Passenger Awareness of Warning

Comment 1:

Good idea!

5.4.1.3 Desired Driver Reaction to Warning

Comment 1:

How does a warning induce rapid recovery of awareness? This guideline may violate known facts about sleep and fatigue. There is no data to support the commentary for this guideline. Finally, if trend indicators are known, they should be used for issuing imminent warnings.

5.4.2.2 Passenger Awareness of Warning

Comment 1:

Then why say NOT?

5.5.1 Automatic Termination of Warnings

Comment 1:

Automatic reactivation sounds like a reasonable feature. However, it is possible that drivers who persevere in driving while drowsy may take longer to arouse subsequent times. The arousing stimulus may also need to be more intense. These factors would need to be considered in warning design.

5.5.2.1 Imminent Crash Avoidance Warnings

Comment 1:

As a point on system reliability, it seems that driver warning systems in general should guard against failure modes where the warning alarm is constantly presented. This could prompt the driver to engage in unsafe in-cab behaviors while in motion (eyes off road and hands off wheel to turn device off) and lead to increased crash risk.

Comment 2:

The driver should be able to do a transient manual override of the warning. The audio signal should continue for nominally 30 seconds, before it shuts off. The driver must be in control.

5.5.2.2 Cautionary Crash Avoidance Warnings

Comment 1:

Drowsiness should always be considered a crash-imminent situation, as mentioned elsewhere. Beyond this, the timing data provided in this guideline are not supported by references.

Comment 2:

Reference supporting this?

Comment 3:

Yes, just hitting the alarm off may provide sufficient keep-awake.

5.6.1 Imminent Crash Avoidance Warnings

Comment 1:

Weak, needs to be self-cal. Waiver those that don't need.

Section 6.0 Headway Warning Devices

Comment 1:

Need tie-in to smart cruise controls.

<u>6.2 Device Activation</u>

Comment 1:

Systems should not be encouraged to preclude warning below 10 mph. This is a prime traffic scenario which has big payoff. Also for Intelligent Cruise Control (ICC), a mode operating below 10 mph would reduce a large number of small accidents during heavy traffic conditions.

Comment 2:

Unless I am mistaken, it appears that the authors are recommending that a headway warning device not be deactivated manually unless the vehicle is traveling below a speed of 10mph. In section 2.1.1.3, however, the authors state that, "The driver should also be permitted to manually terminate electrical power to the device at any time during vehicle operation by means of an ON/OFF switch." I THOROUGHLY agree with the guideline specified in section 2.1.1.3, as opposed to the later guideline for headway warning displays. By allowing the driver to deactivate the system at any speed, we are allowing them the flexibility to overrule the system if it is not functioning properly or if it is serving as a source of annoyance.

<u>6.3 Primary Visual Display Location</u>

Comment 1:

As an example, perhaps the guidelines should mention a Head-Up Display (HUD) as one possible means to accomplish this goal of visual display location.

<u>6.4 Levels of Warnings</u>

Comment 1:

Our research (Hirst & Graham, 1994) indicates that a graded visual warning (an abstract 'traffic light' type display) produced earlier braking by drivers compared to a discrete warning (a pictorial icon of a car). Also, subjects preferred the graded warning over the discrete warning.

Comment 2:

(Encompasses section 6.4.1 and 6.4.2) Although I commend the authors for attempting to establish standards for collision warning system algorithms. I feel that they really need to stress the need for further research in this area! One or two sentences stating that more research is needed is not nearly emphatic enough. I also have to wonder how well a driver will integrate the information from separate time-to-collision and headway displays (as recommended by Horowitz and Dingus, 1992). While the theory may make sense, the ultimate question regarding the success of such a system is strictly empirical.

6.4.1 Imminent Crash Avoidance Warnings

Comment 1:

Lots of alarms in Houston and Dallas traffic.

Comment 2:

The criterion for activation of a headway warning system should not necessarily be based solely on a TTC measure (Graham & Hirst, 1994). We found that subjects did not brake according to a constant TTC rule, but rather some other linear distance against relative speed rule, incorporating the added factor of following car speed. If a warning were to mirror drivers' braking in our experiment, it would activate at a distance equivalent to TTC 3 seconds plus 1 foot for every mph of following vehicle speed. Such a rule would have the advantage of activating when the following car crept up slowly towards the target car, but is not optimal in terms of safety (ie. the required deceleration rate would increase with increasing speed).

Comment 3:

If a warning were to be based solely on TTC, we would agree with the recommendation of somewhere in the 3-5 second range. In our experiments, the overall mean braking point (ie. the latest point at which subjects judged that they would be able to avoid collision) was found to be approximately 4.2 seconds.

Comment 4:

Warnings based on constant headways of 1.0-1.5 seconds are likely to produce a large number of false alarms, as drivers often adopt such headways while feeling in control. For this reason, an auditory display is likely to be too irritating to the driver, as well as informing passengers of the driver's 'error'.

Comment 5:

(Pg. 6-2), Specification of "4-5 seconds" may be premature or incorrect. At 55 mph, 5 seconds is 400 feet, which is likely to be too far away to be an "imminent crash avoidance situation". Also, 400 feet will be hard to produce from a technology standpoint. 2.0 seconds seems excessive as a PRT. In the rear-end countermeasure assessment report, we used 1.5 seconds as a 75th percentile value. 2.0 seconds is about 90 percentile, based on Taoka, 1989 (Taoka, G.T. Brake reaction times of unalerted drivers. ITE Journal. March, 1989, 19-21.). The high specification will lead to excessive false alarms. Do you have to specify a value at this time? Or, can you loosen up and conclude that "3-5 seconds" is a good first cut?

Comment 6:

The warnings in our experiments consisted of a visual display (overlaid on the projected scene to simulate head-up presentation) combined with an auditory warning. A majority of subjects thought that neither the auditory nor visual components were redundant. We would recommend a combination of two or more modalities, although haptic warnings are still to be tested.

Comment 7:

We need to be careful of our terminology. For example, the term "headway" is used to describe distance to a target object. It is my understanding that in highway engineering parlance the term "headway" means the distance between the rear of one vehicle to the rear of the next vehicle, while the term "gap" means distance between the front of one vehicle to the rear of the vehicle ahead. Under "Definition of Imminent Crash Avoidance Situation" in Section 6.4.1 the term "headway" is used. It should say simply "distance". I believe that misuse of the term "headway" is common even among highway engineers. Nevertheless, we should not promulgate the misuse in our documents.

Comment 8:

(Pg. 6-4 to 6-5). I see little potential benefits from cautionary warnings in headway detection systems. The false alarm:hit rate might literally be 1,000.000:1. Moreover, such systems are not technically feasible as they would require ranges of up to 1,300' in highway situations.

Comment 9:

There is NHTSA-sponsored research underway (the performance specification programs) in which accident data are being analyzed to model the effect of IVHS countermeasures (including warnings) for various accident types (e.g., single vehicle run-off-the-road, rear-end collisions, intersection collisions). This research is taking into account the range of real-world accidents as currently experienced. Trade-offs between IVHS parameters (e.g., when to warn) and the percentage of accidents of each type that would be reduced are being calculated. This data would be useful (when available) in understanding the tradeoffs between false alarms and alarm effectiveness. I believe this data should be included as part of this guideline document. It should be noted that these efforts are in their early phases and the final results will not be available until some time in the future.

Comment 10:

In addition to warning when headway is one second or less, there should be a warning when speed of the target object is less than 80 percent of the speed of the host vehicle to account for those situations of stopped or very slow moving vehicles in the path of travel but more than one, two or three seconds away.

Comment 11:

The driver <u>must</u> be given the control and responsibility to set headway. The minimum setting allowed (manufactures design) should be what human factors studies indicate the leading driver (target) feels is comfortable to him. If this turns out to be 0.8 seconds, then allow the driver to reduce it that much. The imminent crash warning algorithm needs to be based on closing velocity and distance, not just distance as in the report.

Comment 12:

Last paragraph. This is surely an area where the driver should be allowed, at least to select increased warning distances if that is wished.

6.4.2 Cautionary Crash Avoidance Warnings

Comment 1:

Such an advanced warning was seen as useful by subjects in Hirst & Graham (1994). TTC warnings in such situations should not be auditory due to the irritation resulting from a high frequency of false alarms. However, providing some graded visual display before the imminent crash warning caused drivers to brake earlier (ie. respond faster to the imminent crash warning). Similarly, if a warning is given whenever the headway to the target object reaches 2 or 3 seconds, drivers would be constantly bombarded with warnings and lose faith in the more imminent crash warnings.

Comment 2:

Situation: It is unrealistic and technologically not feasible to provide feedback to the driver in situations in which the time to collision exceeds 10 to 14 seconds even on an informational basis. At 60 mph that would equal a range of 880 feet to 1232 feet, far too great to be a practical value in most driving situations.

Comment 3:

First paragraph. At the standard lane capacity of 1800 veh/hr, mean headway is 2 sec. That part of the guideline is unrealistic, though it is true that there would be fewer accidents if the guide were followed. An area for limited or unlimited driver choice?

Comment 4:

The impact of the timing or headway guidelines on traffic flow and throughput deserves further analysis. Furthermore, driver behavior may preclude maintaining the intervehicle distances required for 2-3 second head ways; drivers will cut in when they see a gap that big.

6.5 Control of False and Nuisance Warnings

Comment 1:

Threshold speed of 1 mph is too high and should be lowered to perhaps 5 to 8 mph to encompass those situations involving very low visibility like heavy fog or dust. Ten miles per hour or 14.6 feet per second is excessive in those conditions. As the report states 25 percent of the accidents occur at 10 mph or less -- why eliminate them? On the other hand there should be logic to preclude the excessively high closing rates indicative of oncoming traffic. The fact is, head-on collisions, according to NHTSA, are only <u>2.5 percent of all collision types</u> and to be effective at range, without this logic there will necessarily be a very high false alarm rate on even gradual curves.

Comment 2:

Second paragraph. The problem raised would be circumvented to a degree if the warning device were affected by the speed of the vehicle it was travelling in. This would still leave true head-on collisions unwarned. This may not matter, for what is the increased chance of avoiding a head-on with warning?

Comment 3:

(Pg. 6-5). Instead of citing "Battelle, 1992," cite "Knipling et al." (Knipling, R.R., Mironer, M., Hendricks, D.I., Tijerina, I., Everson, J., Allen, J.C., and Wilson, C. Assessment of IVHS Countermeasures for Collision Avoidance: Rear-End Crashes. NHTSA technical report, publication number DOT-HS-807-955, May 1993) Also, need to correct the wording of these statements. They should be: "25 percent occurred at following vehicle speeds of 10mph or less." and "34 percent occurred at following vehicle speeds of 15mph or less."

<u>6.6 Detection Zone Coverage Area</u>

Comment 1:

What does "in all likely lane positions ahead of the vehicle" mean and what might the cost impact be?

<u>6.7.2 Auditory Warning Displays to Indicate Direction</u>

Comment 1:

For simple speech warnings, there is the potential for confusion in conveying directional information. For example, does "Left!" mean there is hazard to the left, or the driver should swerve left due to a hazard to the right.

<u>6.7.3 Tactile Warning Displays</u>

Comment 1:

See Michon (1993) for a review of tactile displays for headway maintenance.

<u>6.8.1.1 Imminent Crash Avoidance Warning Displays</u>

Comment 1:

Warning should remain in effect until the driver responds, not "or is no longer required." There is nothing to be gained by continuing to warn the driver if he is already responding to the situation by applying brakes other than an annoyance. Is their research or field data to support the conclusion that a driver may stop corrective action without a warning?

6.9.1 Headway Warning Device Sensitivity Adjustment

Comment 1:

Adjustments must be infrequent and easy to accomplish. Older drivers may not remember to conduct the adjustment, nor be capable of understanding the implications of correctly adjusting the sensors.

APPENDIX B

COMMENTS ADDRESSING THE REVIEW & DISCUSSION ISSUES

Appendix B contains responses to 25 questions put forward to a working group session on the preliminary guidelines of the IVHS America Safety and Human Factors Committee at the Annual Meeting of IVHS America, held April, 1994. Participants in the workshop were provided in advance with a set of 25 specific questions to consider. They were also free to provide any additional review comments. The review comments by workshop participants are included with those of all other reviewers in Appendices A and C. Appendix B presents responses to the 25 questions raised for the workshop.

#1 Which specific guidelines are practical or are not practical for system designers to use?

Comment 1:

It is difficult to evaluate applicability of the guidelines due to the very limited practical experience of crash avoidance systems.

Comment 2:

An important factor, which I haven't found referenced in this report, is the time lag between driver recognition of a threat and driver action. Unfortunately, the collision warning system can only recognize driver actions and not their intentions. Could this lead to situations where collision avoidance warnings might actually distract the driver?

Comment 3:

Location of primary visual displays within 15 degrees of the drivers line of sight is unrealistic for an automotive environment. As noted in the rationale, this is an optimum field of view based on MIL standard. In an automotive environment this would practically mandate a HUD.

#2 Which guidelines do you agree/disagree with? Why?

This question is specifically addressed in the comments in Appendix A.

#3 What might be done to the Guidelines content or format (or both) to improve usefulness?

Comment 1:

The final version of this report will need to be well indexed. It will be used as a reference document. It will not be read cover to cover. An index containing key words relating to warning issues, design features, display technologies, etc. needs to be added.

Comment 2:

The report needs to make much more use of illustrations: tables, figures, and bullet lists, bold face or italics for phrases, structured writing/information mapping, blocks, etc. to enhance the presentation and break up the text. Tables could have columns for design recommendation, limits of applicability, and specific references to other documents such as MIL-STD-1472D. Standard formats for this should be used throughout. This is currently done in the text. Also graphs showing relationships of interrelating parameters would improve the reports' effectiveness. For example, in Section 6.4.1, the relationships of various reaction times and accident mitigation action times (detect, recognize, decide, ..., and stopping distance) could be shown along a time line graph (perhaps showing differences across age groups as well as average times) rather than as text.

Comment 3:

The Guidelines should be made easier to use (i.e., find information desired). I recommend a quick-look checklist at the beginning of each section, or in an overview quick summary section. This will make it possible to see at one glance how the section/report is organized and the general recommendations and distinctions made for each section. Table 1 shows how such a checklist might appear for Section 2.1 of the report.

Table 1. Example Format for Section Overview

General Guidelines	**Checklist**	**Sect-ion**	**Pg.**
Device Activation & Deactivation	! Power system to standby at ignition. ! Activate sensor only when conditions warrant. ! Terminate power when vehicle turned off.	2.1.1	2-1
Device Testing	! Must have built-in-test. ! Must indicate failure condition. ! Allow driver to test alarms. ! Allow driver to adjust alarms. ! Design for fail-safe operations (e.g., failure must not result in alarm).	2.1.1	2-2
Parameter Initialization	! Indicate non-default settings at ignition. ! Allow parameter adjustment	2.1.3	2-4
Levels of Warnings -Imminent Crash -Cautionary Crash Warning	! Immediate control response required ! Must use at least two modes (visual plus auditory and/or tactile). ! Immediate attention required. ! etc.	2.2.1 2.2.2	2-5 2-6

Comment 4:

Suggest use of non-right-justified text. I believe that human factors research has found that non-right-justified text is easier to read and use than right-justified text.

Comment 5:

The "fog count" of the text narrative seemed high. Consider editing to reduce sentence length, remove unnecessary prepositional phrases, etc. Suggest that you determine the "fog count" or other measure of reading difficulty for the document, and then edit accordingly.

Comment 6:

I found the "labeled" bullet items (e.g., the series on pages iii-v) easier to comprehend than the "unlabeled" ones (e.g., pages ii-iii and 2-11).

Comment 7:

The term "crash" is preferred over "accident" unless you are referring to "accident databases".

Comment 8:

The addition of section numbering would make the document easier to follow. Also, suggest repeating the main heading in each subheading; e.g., 1.1 General/System Research Needs: Optimize Standard Warning Signal for Each Presentation Mode.

Comment 9:

I am concerned with the apparent strategy utilized. It appears to me that the approach was driven by the availability of literature, with guidance provided where possible. As a consequence, (I preface this remark with the comment that this is in no way a reflection on the contractor(s) who performed the study--and would be considered out of the scope) it would appear that technical inputs were not driven by integrating system alarm/fault requirements with user requirements, and therefore may be incomplete. Perhaps, the use of an IVHS task analysis, fault tree, state transition diagrams, and/or failure modes and effects analyses would result in the identification of all nominal and contingency alarm conditions. The basis for making specific guidance would then be based on system and user requirements.

Comment 10:

Knowledge basis for guidelines. The paper identifies, with commendable accuracy, the areas where guidelines are needed, and then does as well as possible in the present state of knowledge. This inevitably produces guidelines of variable weight. To a degree the text already does this. However, it would be better if a scale of certainty were introduced, ranging from "Guideline derived from statistically valid studies in the field" through "based on extrapolation from laboratory experiment in similar area" to "common-sense reasoning by people familiar with human factors". The level of certainty should then be quoted with each separate guideline. To make a start I suggest that, while they are all well reasoned and are the best that can be said now, the following guidelines are among those least well supported by objective evidence: 2.3.3, 3.3, 3.7.2.2, last paragraph, 4.3.1, 4.4.2, 5.5.3.

#4 For a given guideline (or set of guidelines), can you provide a counterexample to indicate circumstances where it may not be appropriate?

This question is specifically addressed in the comments in Appendix A.

#5 For a given guideline (or set of guidelines), what are your concerns?

This question is specifically addressed in the comments in Appendix A.

#6 What would be the "top" research issues you would recommend for immediate research support to further the state-of-the-art in CAS design?

Comment 1:

Manual Override. The "two-click" turn signal method described above in comments on the guidelines would be one method of addressing this problem.

Comment 2:

An important area for further research is alarm modes. Which are the most effective in communicating information to the driver? Should audible tones be harsh or soft, melodic or a single clear tone or male or female voice? These are important questions related to the effectiveness of CAS.

Comment 3:

(Pages 8-10?) Driver RT distributions. Discussion should address the work by Taoka (attached) who posited a lognormal distribution for reaction time. Is the lognormal distribution universal to all RT situations (with only the parameters changing)? (Taoka, G.T. Brake reaction times of unalerted drivers. ITE Journal. March, 1989, 19-21). Also, driver RT distributions and non-reaction response time distributions (e.g., lane change times) seem to be completely unrelated issues requiring different research approaches. Suggest separating them in the report.

Comment 4:

(Pages 10-11?) False and nuisance alarms. Suggest that the concept of "perceived crash threat" versus "actual crash threat" be discussed, along with conceptual diagram (provided in earlier meeting). The simple dichotomous signal detection model may be misleading and limiting for conceptualizing warning system false alarms. Any situation that might be perceived as a threat is valid for issuing an alarm. Using this conception, it can be shown that perceived false alarm-to-hit ratios may be much less (and thus more acceptable) than actual false alarm-to-hit ratios.

Comment 5:

(Pages 8-10 and elsewhere?) There does not seem to be an explicit recognition that, for many crash avoidance situations, warning parameters will have to be set arbitrarily, knowing that a portion of the driver/vehicle population "cannot be saved". For example, given Taoka's lognormal distribution of RT, the system may "assume" a 60th percentile (1.21 seconds), 80th percentile (1.62 seconds) or 95th percentile (2.01 seconds). Higher values would maximize effectiveness but at the expense of more nuisance alarms. Lower values would prevent fewer crashes but would reduce nuisance alarms (however defined). The same logic can be applied to assumptions about vehicle performance parameters; e.g., braking deceleration rate. The determination of "system assumptions" about drivers and vehicles is a major research issue.

#7 What guidelines should be the basis for future standardization of warning system designs to help ensure safe and effective driver performance in unfamiliar vehicles?

Comment 1:

We must be careful to consider the current driving environment with driving cues which people have come to expect over many years of driving. Auditory cues and flashing indicators are now frequently used for status displays - turn signals, hazard lights activated, seat belt not fastened, door ajar, etc. Future conditions may also be appropriate, for example audible cuing to navigation instructions (upcoming turn, congesting). System status checks which are conducted when the ignition is turned on frequently use the same indicator as the warning light, they are generally red (not green as proposed) but most people have come to understand this. Some FMVSS may also be impacted by these guidelines. The impact of these guidelines on current vehicle standards must be carefully considered.

Comment 2:

Section 2.4.5: Characteristics of acoustic displays is a prime area to make a standard to define the specific auditory characteristics of each required auditory signal.

Comment 3:

Section 2.5.1.2.3: There needs to be standards for the Icons/Pictographs for CAS system. The need to be the same for all vehicles.

Comment 4:

Fault conditions. Do we not need some advice about what warning devices should not do, even if faulty? Such guides are needed if "fail-safe" design is to be possible, as is required.

#8 Should warnings tell the driver what to do for crash avoidance? If so, what are the implications from a product liability standpoint?

Comment 1:

The use of collision warning systems type equipment assumes that the users know what the desired response is to the alert. What are the expectations about the frequency of alerts and how familiar the process would be to the user? What is the anticipated response to alert and how does this bear on the specifications for timing of the alert? Should a message be a warning or a recommended corrective action? What does the warning communicate relative to the corrective action needed in differing operating conditions, such as high speeds versus congestion?

Comment 2:

My initial feeling is no. In-vehicle warnings should draw attention to the situation. It should be up to the driver to decide appropriate response. However, there may be some situations where more prescriptive approaches are warranted. As far as the liability aspect, we should consult a lawyer.

Comment 3:

Definitely not. There are too many variables involved to allow the system to tell a driver what to do. Research indicates that more than 50 percent of vehicle accidents involving driver error are caused by the driver failing to recognize a hazard. Collision warning systems address this problem directly.

Comment 4:

In all cases it is up to the manufacturer. If he is confident of the robustness of the performance of his system, he may care to take the liability risk. I would assume, for the near term, manufacturers will not have the experience and hence confidence in the systems to design them to tell the driver what to do in situations. In the future, however, I expect that system will do it.

#9 Is the probability of two or more simultaneous imminent crash-avoidance warnings high enough to worry about the need to worry about prioritizing them?

Comment 1:

Conflict with other IVHS devices. We can deduce that, e.g. direction indications which are part of a route-finding service, should not be red, especially if they share the display screen with a collision avoidance device. But more express guidance is needed about what other devices should not do. (I recognize that this may lie outside the terms of COMSIS's contract.

Comment 2:

I believe the answer to this is yes, but I think that more research and analysis may be needed. I believe that there may be important multiple imminent potential crash situations that a warning system may have to deal with. In fact, these may be correlated. An example, I gave earlier was a vehicle stopped at an intersection showing a green light with a vehicle illegally entering the intersection on the crossing road. In this situation, an attempt to go around the stopped vehicle could lead to an accident with the crossing vehicle. This is an isolated example. More situation specific analysis is needed to fully determine the best approach for the multiple alarm situations.

Comment 3:

No. One auditory signal to indicate an imminent crash warning. Visual information to indicate the multiple problem. The driver takes the responsibility to decide what to do. Even over the next few decades, I would predict that our CAS systems will be quite incapable of deciding which impending crash has the worst consequences.

#10 Is it a good idea to let drivers turn down the intensity of a warning? Some will likely turn it down all the way.

Comment 1:

One of the big differences between consumer products generally and the job-specific products studied, is the litigious environment which we must deal with. This is of particular concern in the automotive market. We must not only consider the functionality of the system but also the ability to make the system "idiot-proof" based on the user population. Of course we know this is impossible since idiots are so ingenious, but we must make every effort. Controls like manual override switches are sensitivity switches that expose the manufacturer to potential system misuse and misinterpretation as well as increased driver workload. In addition, the space available on the instrument panel to locate these controls is very limited. Considering just the systems outlined in this report could require 10 switches. It is unrealistic to expect the average consumer to understand and adjust the system based on his driving conditions.

Comment 2:

User adjustments. Suggest mentioning the possibility that user adjustment could be automatic; e.g., the system measures your reaction time and braking deceleration pattern and adjusts system sensitivity automatically (but still with the capability for manual override). Of course, the automatic "baselining" approach would require some sophisticated algorithms to accomplish the baselining.

Comment 3:

Yes. My initial feeling is that it should be possible to adjust intensity within a predefined range, but not be possible to turn an alarm off. I think this needs to be discussed, and the pros and cons fully explored before a final conclusion is drawn, however.

Comment 4:

Yes, but not below some minimum level particularly in commercial vehicle applications. A device that adjusted the volume of audible warnings based on the ambient noise level would be most appropriate to commercial applications.

#11 What is a good definition of a false alarm?

Comment 1:

An alarm given without sufficient basis in the real-world situation. See above for a suggested definition of false alarms and nuisance alarms.

Comment 2:

An alarm presented to the driver when no imminent or cautionary crash situation exists and the alarm provides no useful information about the driver's immediate traffic environment.

#12 Multiple warning levels means sounding an alarm under non-alarming circumstances. Should we be concerned that these will quickly become a nuisance? Is this a discussion that can be intelligently pursued without an analysis of the kinematics of the crash situation?

Comment 1:

No. In commercial operations, a CAS that uses a multiple warning level system can actually provide two functions. Besides providing the driver with warnings about impending hazards, the multiple warning level can help to modify driver behavior to maintain safer headway distances. Even drivers with many years of service sometimes do not have a good understanding of safe following distances. A CAS that provides a staged, multi-level warning system provides a useful training and behavior modification tool.

Comment 2:

If the warning system is designed such that it will quickly become a nuisance, then we designed the system incorrectly and we better be concerned. Also, if we need significant analysis of the kinematics of the crash situation, then we again designed the system incorrectly.

#13 Do we really need redundant, dual mode warnings?

Comment 1:

The proliferation of redundant displays, audible and visual for many systems and functions is also unrealistic and unnecessary or in some cases inappropriate. For example, do you really want to distract a driver with a visual display when he is being warned of an imminent frontal crash? For blind spot warning, is it necessary to provide a visual display and a directional audible warning? Redundant displays should be limited to situations where additional information is helpful in assessing the situation and making a timely decision.

Comment 2:

I believe dual mode alarms are a good idea for a number of reasons. First as you point out, auditory alarms do not depend on whether the driver is attending to the alarm source, as is the case with visual signals. However, although auditory alarms are good at eliciting attention, they are very limited in the amount of information that can be conveyed quickly. An associated visual signal could supplement the attention getting quality of the auditory alarm. Also, as you note there are people in the population who may be hearing deficient. An integral visual alarm would be useful for these people. Finally, I believe that it is possible to know the general direction of visual attention for alert drivers. Visual gaze direction samples will include many saccades in the forward area. Visual alarms in this general area will be relatively effective, I believe.

Comment 3:

No.

#14 Can speech be appropriate for an imminent collision warning?

Comment 1:

Yes, I believe so, if properly designed. The use of speech needs to be compared with other approaches under consideration within the context of the situations being warned about (e.g., how much time is available for delivering the warning?).

Comment 2:

No.

#15 Is there adequate technical basis for the recommendations given that they were developed without any kinematic analysis of the crash situations?

Comment 1:

The general guidelines are fine, but the guidelines dealing with specific crash situations would greatly benefit from analysis of crash causes (this is noted above).

#16 Does this report do an adequate job of identifying the significant unresolved issues that need to be researched?

Comment 1:

No.

#17 Does a 'cautionary' warning - for example, for low friction - really differ from a status display? Does the driver distinguish between cautions and warnings?

Comment 1:

Yes. Cautionary warnings relate to potentially dangerous highway and/or environmental conditions, while status displays merely display the status of conditions (environmental or in-vehicle). Also, warnings relate to imminent dangerous conditions that require immediate action. Associated warning signals must be attention-getting for this reason. Cautions, on the other hand, relate to potentially dangerous conditions, but do not necessarily require immediate responses. I believe in-vehicle warning systems must provide for both levels of alarm.

#18 Are these guidelines in accordance with your model of driver's cognitive processing of warnings and crash behavior?

Comment 1:

My model, based on long experience in road safety experiment and research, is that "there's nowt so queer as folk". However, clever we are before the event, there is a significant probability that most or some people will react in an unexpected way. Further they will modify their behavior in response to the CAS device, and the modification is rather more unpredictable than the first response. Still we do have to do our best, and this paper is a reasonable start.

#19 Do we know enough about driver pre-crash behaviors to propose human factors design guidelines to design devices compatible with them? If not, what don't we know?

No response received.

#20 Across different crash circumstances, is there anything common that might be addressed in the Guidelines?

No response received.

#21 What are the main functional criteria by which Crash Avoidance System (CAS) warning effectiveness should be evaluated?

Comment 1:

The detail performance characteristics of audible and visual warnings will need to be refined based on applications (low speed, high speed, front, rear) on the vehicle. I think you will agree that there is adequate time to provide back-up warnings in various "creative" forms. However, forward warnings at highway speeds is a different matter and fractions of a second could be the difference between life and death. Here the warnings must provide instant recognition and action by the driver.

Comment 2:

Perhaps the most important technical issues are accuracy, reliability and uniformity of performance from car to car and under all environmental conditions. Performance here also includes the driver interface. Finally, if drivers are to have confidence in crash warnings, they need to be as totally reliable as possible.

Comment 3:

Evaluation should include consideration of the behavior elicited across the range of driving situations and driver categories.

Comment 4:

There is no substitute, in the end, for observations in the field, post-deployment. It does not have to be a national or State-wide study: indeed it is better to use a small, properly selected sample. Such a study needs very careful planning, taking account of statistical variation (a control sample will be needed). There is no experience of doing such a study in this field. There are institutional problems. Not easy but possible, for I have done it in my own country.

#22 What are the implications of driver training requirements of the guidelines?

Comment 1:

Effective driver training, especially for commercial drivers is very important. Specifically they must understand the system's capabilities and its limitations.

Comment 2:

Throughout any guideline or standard, a basic precept must be to minimize driver training, and make the system as simple and intuitive as possible. I don't think this is embodied in this first guideline.

#23 Is there, from the driver's standpoint, a distinction between warnings and cautions?

Comment 1:

Yes, see above. I believe it is important to include warning and caution categories in the warning system (I agree with COMSIS on this).

Comment 2:

No, it would be confusing. There should be a "caution" and an imminent crash warning.

#24 Is it true that no warning modality will be effective in all cases? Is it true that some modalities will be better than others in most cases? Worse than others in most cases?

Comment 1:

Yes, see above. This is why I believe that dual modality alarms are preferred (I agree with COMSIS in this).

#25 Do you believe CAS warning guidelines are advisable at this time? Why or why not? Is standardization advisable? Why or why not?

Comment 1:

Guidelines are advisable. We know enough about general human perceptual capabilities and warning design in general to provide useful guidelines. Without such guidelines commercial warning products are likely to range from ineffective to fear-producing. Standards are probably premature at this time (except perhaps at a very high level). I believe that standards should be developed after we have a more complete research base within this domain. Perhaps an outline for such a standard should be developed now as an approach to guiding the needed research.

Comment 2:

I believe it is absolutely crucial that standards be implemented as soon as possible. Much of the future acceptance of IVHS systems will be shaped by the acceptance of the initial systems which are deployed. For the initial systems, there will be a significant learning curve for the driving public before the systems are utilized and accepted. If there are not standards to make the human interfaces (displays and controls) nominally the same from one car to the next, the driving public will be confused and the acceptance will be hindered. It will also result in greater litigation, standards, there will be less confusion, and hence fewer accidents. the IVHS community has an obligation to address this new frontier is as safe a manner as possible. There may be argument that we don't know enough now about CAS systems to put standards in place now. This may be true for some of the sensors, and performance standards, but the human factors aspects, which we are addressing here, in most cases are independent of the sensors, and we have sufficient enough knowledge to support guideline standards, such as in the COMSIS report, to cover 90 percent required standards. We need to implement the standards as soon as possible, before systems that don't comply are fielded or some defacto standard emerges which is not as well thought out as an industry consensus standard.

APPENDIX C

GENERAL COMMENTS

Appendix C contains general comments that do not fit into either Appendix A or Appendix B. This appendix is divided into two general divisions: organization and format comments, and general comments.

Organization and format comments

Preface

Comment 1:

The Preface provides an excellent introduction to, and overview of, design issues. In fact, it should be called "Overview of Design Issues" or something like this.

Comment 2:

Some of this preface material should be included in Section 1, since the material may affect how individuals use this document.

Table of Contents

Comment 1:

This needs to go to the lowest level of entries, since it's the first place a user will look to find where to read to get his or her answer.

Comment 2:

I am unprepared for seeing a table of contents (at the start of each section). A casual user would assume a misprint.

<u>2.2.2 Definition of Cautionary Crash Avoidance Situation</u>

Comment 1:

Provide the "criteria" mentioned in the first sentence, in bullet form here for the reader.

<u>2.3.6 Prevention of False/Nuisance Warnings</u>

Comment 1:

Simplify and shorten this section.

<u>2.4.5.2 Fundamental Frequencies</u>

Comment 1:

Where 1472D applies, just reference.

<u>2.7.2.1 Labeling</u>

Comment 1:

"For detailed recommendations on labeling, see MIL STD-1472D, Section 5.5, Labeling." Repeat that section here or in an appendix to this document; don't make the reader go to another source.

<u>3.1 Blind Spot Warning Device Application</u>

Comment 1:

Provide a figure.

<u>3.5.1 Area of Coverage</u>

Comment 1:

Last paragraph. Give figures.

4.4 Backup Warning Device Levels of Warning

Comment 1:

"This is an exception to Section 2.2." Give section title as well to help the reader put this in context.

Comment 2:

Rationale, first paragraph. Some may object that the example is not gender-free.

4.4.1 Imminent Crash Avoidance Warnings

Comment 1:

Rationale, third paragraph. Provide the quantitative data.

4.8 Detector Sensitivity Adjustment

Comment 1:

"...in section 2.7". Give section title.

5.4.2.1 Warning Ambiguity

Comment 1:

"See section 5.4.1.1 for rationale" Repeat the rationale here, make it one step reading for the user of these guidelines.

5.6 Detector Sensitivity Adjustment

Comment 1:

"In section 2.7", give section title.

6.4.1 Imminent Crash Avoidance Warnings

Comment 1:

"Features...see sections 2.4.1, 2.4.6...." Give section titles.

6.7.1 Visual Warning Devices

Comment 1:

"in section 2.3.3", give section title.

6.9 Controls/Adjustments

Comment 1:

"in section 2.7", give title and/or page number.

General Comments

Comment 1:

The new guidelines should be able to fit, as a detailed insertion, into the COMSIS guidelines to provide additional specificity.

Comment 2:

Many of the guidelines would be easier to understand if they were presented in a decision tree format or a structured format: if x, then y.

Comment 3:

My overriding comment/concern is that the report is too wordy and not conducive for the way it will be used, i.e., as a reference.

Comment 4:

The document tends to be choppy and repetitious making it very difficult to read. Occasionally wordy with God & motherhood or common sense statements.

Comment 5:

(In rationale), give references for the interested reader. This will also help the reader understand the strength of the guideline - based on hundreds of studies or on best judgement?

Comment 6:

Needs a recap of research needs scattered throughout the document and an integration of research requirements in one section.

Comment 7:

I need a section that tells me how to use this document to find what I need. A "how to use the guidelines" document should include an example. An index is essential. Tabbing the sections would be useful (but expensive). Providing a hypertext document would be best.

Comment 8:

I need a description of each section's organization (a roadmap) to help me find the information I need. Something like "this section contains four parts, the first describes...".

Comment 9:

Request that any citations of "Battelle" or "work done by Battelle for NHTSA" be replaced with specific citations of reports.

General Positive Characteristics

Comment 1:

Hard design guidelines are most useful (e.g. red, flashing @ 5 Hz, ...)

Comment 2:

The report seems to cover all conceivable alert and warning modes in the different crash situations described.

Comment 3:

An excellent appreciation of the human factors issues and concerns for in-vehicle warning devices.

Comment 4:

The guidelines are reasonable in level of detail. That is, they do not specify exactly what kind of warnings should be used and exactly how they are to be displayed. But they apply principles that have been established in the literature to assist designers in making appropriate design choices.

Comment 5:

I would like to commend the authors on providing the audience both guidance and a rationale statement. This approach provides those unable/unwilling to adhere to the "letter of the law" an opportunity to understand the underlying issue(s) and more importantly to make design tradeoffs within the constraints imposed by their respective design process(es).

Comment 6:

The report gives clear recommendations about normal operation of IVHS warning devices. Many of them are insightful and illuminating. I was particularly impressed by the treatment of the relative utility of visual and aural warnings.

Comment 7:

The guidelines provide a very thoughtful approach to the problem of multiple possible warning signals competing for driver attention with a variety of other informational devices and services contemplated under IVHS. In addition, the authors have culled human factors insight from a variety of settings (military, aviation, workplace etc.) and have appropriately considered the context in which the warning will arise during automobile operation. Equally important, they have raised the issue of a diverse user population. We especially appreciate reference to issues that cannot be resolved further without a research base.

Comment 8:

Overall I found the advice to be explicit, sound and well-justified. The report synthesizes a huge amount of research data and summarizes the state of our current knowledge very well. The report is authoritative and will be a major contribution to IVHS warning system R&D.

Comment 9:

Overall, the report accomplishes its goal of capturing a number of critical issues.

As such, it can form the basis for major programs of R&D on warning systems. Most issues are described explicitly and authoritatively. It will be a very useful report.

Comment 10:

First, I must compliment COMSIS on a very good review of currently available literature on crash avoidance warning devices and the development of a fairly complete "strawman report".

Comment 11:

Frequently in the report, it is very appropriately pointed out, that false and nuisance alarms and warnings have to be kept to a low level for collision warning systems to be accepted by drivers.

Comment 12:

The guidelines are a "step in the right direction" to define needs and expectations both from an industry standpoint and uniformity of performance for drivers.

Comment 13:

The explanatory portions of the report contain very interesting rationale and background information to support the Guidelines.

General Negative Characteristics

Comment 1:

It should be made more clear where recommendations are well founded on prior research, and where they are based on speculation and assumption.

Comment 2:

There are areas where the recommendations may not have a sufficiently sound basis or where scientific research findings have not been adequately represented.

Comment 3:

I realize that the focus of this report is on general criteria to use to consider the adequacy of collision avoidance warning devices. However the report should state more boldly where the knowledge base is adequate or inadequate. This is done but lacks sufficient emphasis.

Comment 4:

It seems that in parts of this document where specific parameter values are provided for human perceptual capabilities and reaction times, that variations across population subgroups (especially age) are not given. Data presented should include an indication of how the parameters are affected by population subgroups (e.g., across age groups). It seems that such presentations will be important in designing the ranges of display adjustments and sensor sensitivities. Should consider adding tables that show these relationships.

Comment 5:

As an ancillary concern, there should be specific attention to the possibility of enhanced risk taking and indicate if there is any data on this issue (which I do not think there is.) These devices, in particular driver alertness devices, may lead users to assume more risk taking because of a perceived need for lessened vigilance.

Comment 6:

Using these devices in the variety of operating conditions is mentioned at some points but there should be statements about what is known and what is not known about varying operating conditions, including traffic conditions. What correction factors are needed to use collision warning devices in varying operating conditions, such as fog and other weather situations, night, or different light levels.

Comment 7:

The issue of setting and individual deficits; i.e., hearing aides, language, color blindness is mentioned at different points but is not sufficiently addressed. It is important to differentiate between professional and nonprofessional drivers. The report makes implicit reference to use of these devices by professional drivers by referring to the DOD standards and to commercial applications which use the blind spot and back up warning devices. Driver characteristics extracted from the DOD database and the commercial applications differ from the civilian capabilities (80 year old drivers) and experience (ex. children playing on driveways). This report should indicate where there is insufficient data on the use of devices by nonprofessional operators.

Comment 8:

In some topic areas there are specifications given for reaction times but who are the subjects of other studies?

Comment 9:

As you know, the systems available in the automotive market are very limited an therein lies a significant limitation of the report. Although many of the guidelines are well documented, the references are often from military standards or aircraft applications. As well noted in the Preface "one of the striking findings was the uniqueness of the vehicle crash avoidance warning situation. Warning practices from other areas were inappropriate because of some important differences from the present application."

General issues

Comment 1:

(Pages 24-25?) Changes in driver behavior. In addition to the risk compensation effect discussed, another very intriguing research question is that of "serendipitous benefits" I believe that this effect will be significant if systems are turn-signal-activated (which I believe they will be). A fuller explanation of this idea follows: If systems are turn-signal-activated, there is an intriguing possibility of "serendipitous benefits" resulting from system use. A turn signal activation requirement might increase turn signal use for lane changes significantly. Since turn signal use conveys subject vehicle driver intent to other drivers, an increase in turn signal use would likely produce crash avoidance benefits in itself - independently of the effects of the sensor/warning/control system. Experimentally, it may be difficult to separate the direct benefits of the sensor/warning/control system from the "serendipitous" benefits of increased turn signal use.

Comment 2:

It needs to be remembered, reading the recommendations, that it was no part of the terms of reference to be sure that the guidance given is realistic. It may not be possible to meet all the recommendations without violating some other constraint - e.g. that the device will not interfere with the deployment of air bags, or cause injury if an occupant bangs into it during an accident. But we do still need to know what the best human factors practice would be.

Comment 3:

There is one philosophical difference I have with the guideline. In most cases, this guideline is reluctant to give the driver the options of controlling the outputs of the CAS system. Also, and more importantly, it does not address the driver adjusting the sensitivity of the CAS system (which probably is related to false alarms and missed detections). I think it is imperative that the driver has the option/responsibility for these adjustments. If the driver cannot "tune" the system to her or his driving habits (age, gender, driving conditions, drowsiness, traffic environment, etc.), there will not be an optimization of its acceptance. If the products are not highly accepted initially, sales will suffer, and the IVHS options on vehicles will not be continued by the manufacturers. A more significant effect will be that of litigation. If the driver is not responsible for the settings (taking them from the most conservative setting at power up to his particular selection), then the manufacturers are fully responsible for how the system operates. If the vehicle is in an accident, and the CAS system was in use, the failure of the CAS system to prevent the accident will rest primarily with the manufacturer, not the driver. From a litigation standpoint, I do not believe the manufacturers will deploy systems which operate this way. The driver must be in the loop, setting the CAS parameters and taking full responsibility for driving. The guideline and standards must support this position. Also, I disagree with the details of the

prioritization of multiple warning. The driver needs and can handle only three levels:
a. The highest level is crash warning (auditory & visual required), which is equivalent to the reports imminent crash warning. Voice is not acceptable (disagrees with 2.4.1).
b. The next level is "caution". This is equivalent to the yellow traffic light. Drivers understand caution. The notification to the driver of the onset of such a situation should be a short auditory (the same auditory signal for any CAS system in the vehicle, although position of the auditory signal source aligned with the problem is excellent) to get the drivers attention, and the remainder of the time the condition exists, a visual display will provide the more detailed information of what and where. (this disagrees with 2.4.2 and 2.4.5.1)
c. The third, and lowest level, is status information. The status information for all CAS systems should be grouped together. They do not need to be within 15 degrees of the drivers normal line of sight. When the status of a CAS system changes, a short auditory notification to tell the driver that the status of a significant system (CAS) has changed. The auditory signal needs to be different than either of the above two. It probably should be the same auditory signal which means check status for any system.

Comment 4:

What ever is picked for auditory signals for these three levels, should be the same for all manufacturers, all vehicles. Individual vehicle custom sounds is much less important than the safety aspects of commonality and a single learning curve for all vehicles.

Comment 5:

False and nuisance alarms. The point seems to have been missed that a warning when in fact there is no danger, may in some circumstances be a useful assurance that the device is working. If all the alarms were true, years might pass without the device operating. Human factors guidance on when the device should warn is very necessary. On the other hand, potential false-alarm situations occur very much more frequently than real-alarms. For example, if the device were to say "impending collision" to as many as 0.1 percent of vehicles on the opposing carriageway, the false alarms would dominate the true ones.

Comment 6:

The preface to the report seems to emphasize that there will be little consistency from vehicle to vehicle in terms of which warning systems are present. However, eventually there will likely be safety standards that specify required and/or permitted systems. Perhaps the report should at least allude to the possibility of future safety standards to ensure consistency of warning system number, type and design.

Comment 7:

"Fail safe" issue must be addressed in the context of each system type; e.g. backing and headway systems may require different "fail safe" rules of operation.

Comment 8:

The potential for an auditory warning to be disorienting after drowsiness is mentioned but needs more consideration. What is the range of people's responses to auditory alertness monitors now?

Comment 9:

How frequently are these devices likely to be used and could there be lack of familiarity with infrequently used devices that require responses within one and one half seconds?

Comment 10:

The issue of measuring driver alertness seems to depend on accuracy of the calibration for alertness. What is the error tolerance and what is the range of individual variability in this area?

Comment 11:

Finally why is there no reference/listing of VORAD and Eaton-VORAD published papers in the bibliography since this is the nation's only headway warning system being actively manufactured, marketed and sold?

Comment 12:

(Page 36?) Reference citation for Toyota Advanced Safety Vehicle?

Comment 13:

(Page 43?) 2nd paragraph. Cite Knipling et al. (1993) rather than "current Battelle work".

Comment 14:

The many limitations shown for backup warning devices suggest they may be only useful as parking aides. If used as collision avoidance devices they may give a false sense of security because of the many limitations identified on their utility. There is insufficient knowledge about this element of the driving task which includes a multitude of issues as it is a difficult maneuver.

Comment 15:

In reading some parts of the report, I get the impression that the collision warning system may be more competent in assessing the traffic situation than the driver. Will this be true in the foreseeable future?

Comment 16:

Variation between people. The report nowhere refers to variations between different people's reactions and skills. This is particularly unfortunate where a quantitative recommendation advises, e.g., on "safe settings" for following distance. The right distance at which different people will need to be warned will vary between people. The DRIVE finding that some people at least, tend to follow just outside the warning limit, reinforces the significance of this.

Comment 17:

Does the present state of knowledge on the human factors side make it possible to say in which situations, if any, "false" alarms would be reassuring. Can we put limits on the humanly acceptable frequency of the false alarms? or define measurements which would do so?

Comment 18:

Color. The guidelines assume that all visual warning devices will be in color. Is this justified? Is it desirable, and if so, how desirable?

Comment 19:

I wonder about the utility of some categories of collision warning systems. If multiple collision warning systems are installed, the user may not be able to distinguish between them rapidly. Think about the need for and use of crash avoidance devices from the user's point of view, for example, think of devices as a general category or feature providing an alert. Incorporate categories of devices in a transparent way hidden in the software and use the interface to tell the user where to look.

Comment 20:

European researchers (the PRO-GEN group within the PROMETHEUS project) estimated that the expected benefit from EMERGENCY WARNINGS is minimal or negative. They claim that automatic intervention seems to be the only effective way to improve safety. See for example Table 7.1 in Berthold Farber's chapter "Determining Information Needs of the Driver, in the recent book by Parkes, A. and Pranzen, S., Driving Future Vehicles, Taylor and Francis: London and Washington, DC, 1993, 69-76.

Comment 21:

If the European researchers are correct in their estimation, there is promise in an area not covered by the COMSIS report: a semi-automatic system which partially controls the vehicle and indirectly warns the driver. The best example is the ICC (Intelligent Cruise Control), which through automatic throttle control and transmission downshift provides the driver a haptic "seat of the pants" warning. It may be that such warnings will reduce the need for emergency warnings.

Comment 22:

The option for tactile warnings are noted in several parts of the report (e.g., 2.2.2, page 2-7). However, the current state of knowledge about tactile warnings is limited (as stated in Section 2.4.1). For this reason, the option for tactile displays, when noted, should be de-emphasized. Perhaps noted as another alternative that could be considered but that research support for design of such warnings is limited. Could also consider displays using the haptic sense (rather than just tactile) to include both Cutaneous and kinesthetic cues (e.g., would large movements of the steering wheel wake a sleepy driver better than vibrotactile approaches?) Of course, the term haptic is less colloquial than tactile. If the audience for this document is other than human factors professionals, a term like haptic may need to be defined or substituted for more descriptive text.

APPENDIX D

ACRONYMS

Appendix D contains a list of acronyms found in the body of the guidelines, as well as Appendices A, B, and C.

AAA	American Automobile Association
AASHTO	American Association of State Highway and Transportation Officials
BIDT	Built-In Diagnostic Testing
CAS	Crash Avoidance Systems
CCD	Charge Coupled Device
CRT	Cathode Ray Tube
CVO	Commercial Vehicle Operation
DOD	Department of Defense
DRIVE	Dedicated Road Infrastructure for Vehicle Safety in Europe The European Community DRIVE project is program of collaborative research and development to find ways to alleviate road transportation problems through the application of advanced information and telecommunications technology.
EEG	Electroencephalogram
EMG	Electromyogram
EOG	Electrooculogram
FARS	Fatal Accident Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GIDS	Generic Intelligent Driver Support
GES	General Estimates System
ICC	Intelligent Cruise Control
ITE	Institute of Transportation Engineers
IVHS	In-Vehicle Highway System, (currently called ITS)
HUD	Head Up Display

LED	Light-Emitting Diode
LVM	Lead-Vehicle-Moving
LVS	Lead-Vehicle-Stationary
MUTCD	*Manual on Uniform Traffic Control Devices*
NHTSA	National Highway Traffic Safety Administration
OCAR	Office of Crash Avoidance Research
NTSB	National Transportation Safety Board
OSHA	Occupational Safety and Health Administration
PAR	Police Accident Reports
PRP	Psychological Refractory Period
PRT	Perception-Reaction Time
RT	Reaction Time
TBD	To Be Determined
TBF	Time -Between-Failures
TCAS	Traffic Collision Avoidance System
TRB	Transportation Research Board
TTC	Time-To-Collision

APPENDIX E

GLOSSARY OF TERMS

Appendix E contains a glossary of terms found in the body of the guidelines.

Backup Warning Device.

Device which is intended to provide warnings for backing "encroachment" crashes and is distinguished from devices which function as parking aids.

Blind Spot Detection Device.

Device which is intended to alert the driver traveling on a roadway to the presence of all potentially conflicting vehicles located in areas of poor visibility lateral to the vehicle.

Cautionary Crash Avoidance Situation.

A cautionary crash avoidance situation is one in which the potential for a collision requires immediate attention from the driver, and which may require a vehicle maneuver, but does not meet the definition of an imminent crash avoidance situation. A cautionary crash avoidance situation may occur when an object is in a certain zone around the vehicle, such as a driver's blind spot, or immediately behind the vehicle in instances of backing maneuvers.

Cautionary Crash Avoidance Warning.

Cautionary crash avoidance warnings should be provided to alert the driver to a cautionary crash avoidance situation which does not meet the criteria of an imminent crash avoidance warning situation. Cautionary warnings are lower in urgency than imminent warnings, but are still intended to capture the attention of the unaware driver, rather than require deliberate monitoring by the driver.

Crash Avoidance Warning.

A crash avoidance warning is an in-vehicle presentation of information alerting the driver to a probable collision situation requiring immediate attention. A crash avoidance warning is **not** intended to continuously present status information requiring monitoring by the driver, but to capture the driver's attention in a hazard situation.

Crash Avoidance Warning Device.

A crash avoidance warning device is a unit designed to perform a single crash avoidance warning function, for example, headway detection or blind spot monitoring.

Crash Avoidance Warning System.

A crash avoidance warning system is a unit designed to integrate the functionality which would normally exist in more than one warning device.

Driver Alertness Monitoring Device.

Device which is intended to warn the driver when the driver's alertness is impaired below a level that is no longer consistent with safe operation of the vehicle.

False Alarm.

False warnings are those triggered by an inappropriate stimulus event.

Headway Warning Device.

Device which is intended to alert the driver traveling on a roadway to the presence of a slower moving vehicle, stopped vehicle, or object in the forward path of the vehicle.

Imminent Crash Avoidance Situation.

An imminent crash avoidance situation is one in which the potential for a collision is such that it requires an immediate vehicle control response or modification of a planned response in order to avoid a collision. Instances of imminent crash avoidance situations may occur when a driver indicates a change of path that brings it into potential collision with an object, a backing vehicle is in close proximity to a target object, a driver exhibits an obvious indicator of sleep onset, or when a target object is sensed in the immediate headway of the vehicle.

Imminent Crash Avoidance Warning.

Imminent crash avoidance situations exist when there is the potential for a collision. These warnings are more urgent than cautionary crash avoidance warnings and are intended to address time-critical situations.

Nuisance Alarm.

Nuisance warnings are those triggered by an appropriate stimulus event under conditions that are not useful to the driver.