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DOT HS 808 531

February 1997

Summary Report

In-Vehicle Crash Avoidance Warning Systems: Human Factors Considerations

Readers who are interested in reviewing the following reports that were referenced in this summary report, can obtain them from the National Technical Information Service (Springfield VA 22161) or from the Intelligent Transportation Society of America Bookstore (Publications Manager, 400 Virginia Ave SW, Washington D.C. 20024-2730. 202/484-4548, www.itsa.org)

Harpster, J., Huey, R., Lerner, N., and Steinberg, G. (1996). ***Backup Warning Signals: Driver Perception and Response.*** National Highway Trafiic Safety Administration, Washington, DC. DOT HS 808 536

Huey, R., Harpster, J., and Lerner, N. (1995). ***Field Measurement of Naturalistic Backing Behavior.*** National Highway Traffic Safety Administration, Washington, DC. DOT HS 808 532

Lerner, N., Dekker, D., Steinberg, G., and Huey, R. ***(1996). Inappropriate Alarm Rates and Driver Annoyance.*** National Highway Traffic Safety Administration, Washington, DC. DOT HS 808 533

Lerner, N., Kotwal, B., Lyons, R., and Gardner-Bonueau, D. ***(1996) PreliminaryHuman Factors Guidelines for Crash Avoidance Warning Devices.*** National Highway Traffic Safety Administration, Washington, DC. DOT HS 808 342.

Tan, A., and Lerner, N. (1995). ***Multiple Attributes Evaluation of Auditory Warning Signals for In-Vehicle Crash Avoidance Warning Systems.*** National Highway Traffic Safety Administration, Washington, DC. DOT HS 808 535

Tan, A., and Lerner N.(1996). ***Acoustic Localization of In-Vehicle Crash Avoidance Warnings as a Cue to Hazard Direction.*** National Highway Traffic Safety Administration, Washington, DC. DOT HS 808 534

Technical Report Documentation Page

1. Report No. DOT HS 808 531	2. Government Accession No.	3. Recipients Catalog No.
4. Title and Subtitle Summary Report on In-Vehicle Crash Avoidance Warning Systems: Human Factors Considerations		5. Report Date SEPTEMBER 1996 6. Performing Organization Code
7. Author(s) Huey, R.W., Harpster, J.L., and Lerner, N.D.		8. Performing Organization Report No.
9. Performing Organization Name and Address COMSIS Corporation 8737 Colesville Road Suite 1100 Silver Spring, Maryland 20910		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTNH22-91 -C-O7004
12. Sponsoring Agency Name and Address Office of Crash Avoidance Research National Highway Traffic Safety Administration U.S. Department of Transportation Washington, DC 20590		13. Type of Report and Period Covered Summary Report 14. Sponsoring Agency Code

5. Supplementary Notes

NHTSA COTR: Michael Perel, NRD-52

16. Abstract

This document represents the final report of the work performed under contract DTNH22-91 C-07004, "In-Vehicle Crash Avoidance Warning Systems: Human Factors Considerations". This project was performed to develop guidelines for the interface design of in-vehicle crash avoidance warnings and to begin the process of filling some of the data gaps exposed during that definition process. It did not have the objective of designing some specific device or system. Rather, it had the more general perspective of identifying the common issues for the range of potential devices, supporting integration and compatibility among multiple types of devices, aud promoting compatibility among alternative products for a given warning situation. In support of these objectives, tbe project conducted critical analyses, developed preliminary guidelines, and conducted new empirical research on selected issues.

In addition to the guidelines, a series of experiments was conducted, centering arouud two issues: (1) the characteristics of effective acoustic alarms for crash avoidance warnings; and (2) features of effective backup warning devices. The present report provides a brief overview of project activities, and references the interim documents that provide full detail. It also presents a set of human factors recommendations for backup warning systems. This set of recommendations is new and has not been presented in any earlier reports, although the supporting research studies were documented in previous reports.

7. Key Words	18. Distribution Statement
ITS, crash avoidance warnings, alarms, backing, behavior	No restriction. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

9. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	35	

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

Table of Contents

1 .O BACKGROUND

This report summarizes the work performed under contract DTNH22-91-C-07004, "In-Vehicle Crash Avoidance Warning Systems: Human Factors Considerations". This project was performed in an effort to develop guidelines for the interface design of in-vehicle crash avoidance warnings and to begin the process of filling some of the data gaps exposed during that definition process.

With the advent of in-vehicle crash avoidance warning and other driver information systems comes the general questions regarding how each component of this potentially complex system will be designed. The answer, as with many new systems that approach the consumer market, is that many of these system components will be (or are already) designed with little or no consideration for how they will be integrated with other components. These forerunners are often characterized as "technology driven" devices that are to varying extents incompatible with potential users' abilities and expectations for operation. This project was an attempt to understand the likely direction of these potential developments in the crash avoidance warning arena and develop design guidelines that were based in sound human factors principles and/or application specific empirical research.

Some guidance for design exists in aviation and military human factors standards or in guidelines for other technologies. However, little application-specific information existed at the time this project was initiated. Furthermore, the vehicle crash avoidance situation differs in important ways from many of these other applications, and other guidelines are not always appropriate. Therefore the objective of this project was to develop appropriate guidelines for crash avoidance warning devices, to whatever extent existing knowledge and analysis would permit. The project also conducted new research to provide additional guidance for selected issues.

The guidelines and recommendations developed under this project are described as "preliminary", in view of the fact that a great deal of research and development is now taking place, so that a more adequate knowledge base will be continually emerging. However, since product development is on-going, it is important to have available to designers and researchers some guidance based on the best knowledge to date. Furthermore, much of the current research or design activity is focused on a single warning device or application. Yet many of the key human factors concerns stem from the likelihood that there will be multiple types of warning devices in existence at the same time. Therefore the recommendations developed under this project included consideration of how multiple types of warning devices, in combinations unknown at this point, might best be designed so that they work compatibly.

In summary, this project concerned the spectrum of human factors issues related to the design and implementation of crash avoidance warning devices of all types. It did not have the objective of designing some specific device or system. Rather, it had the more general perspective of identifying the common issues for the range of potential devices, supporting integration and compatibility among multiple devices, and promoting compatibility among alternative products for a given warning situation. In support of these objectives, the project conducted critical analyses, developed preliminary guidelines, and conducted new empirical research on selected issues. This research addressed generic issues related to the nature of warning signals and some system-specific issues related to the operational characteristics of backup warning systems.

2.0 OBJECTIVE OF THIS REPORT

This is the summary report under project DTNH22-91-C-07004. A wide variety of activities were conducted during the period of the contract, and these have been documented in detail in a series of project technical reports. The present report has two objectives. First, it provides a brief overview of previous project activities, and references the technical documents that provide full detail. Second, it presents a set of human factors recommendations for backup warning systems. This set of recommendations is new and has not been presented in any earlier reports, although the supporting research studies were documented in previous reports.

3.0 OVERVIEW OF EARLIER PROJECT ELEMENTS

The sequence of project activities is shown in Figure 1. The initial phase of the project provided a comprehensive overview of the human factors issues related to in-vehicle crash avoidance warning systems. In addition to review and analysis of pertinent literature, technology projections, and existing design guidelines, it included collection of new data in a driver log study and an analysis of police accident reports for selected collision types. This phase of the project provided an understanding of the emerging crash avoidance warning technologies, the problems they must address, and the m-vehicle environment in which they will be operating. Following this, work began on a comprehensive set of guidelines for all human factors aspects of crash avoidance warning use. The guidelines addressed general issues relevant to all warning devices, specific recommendations for four selected types of warning devices, and system issues related to the compatibility of multiple types of warning devices. These guidelines went through an external review process that ultimately resulted in a key product of this project, the document titled ***Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices. The*** "Guidelines" document was based on currently available findings and practice, but there were clearly important gaps in knowledge. The final phase of the project conducted new research to address some of these gaps. A portion of this effort was in support of other on-going NHTSA research. Additionally, a series of experiments was conducted, centered around two issues: (1) the characteristics of effective acoustic alarms for crash avoidance warnings; and (2) features of effective backup warning devices.

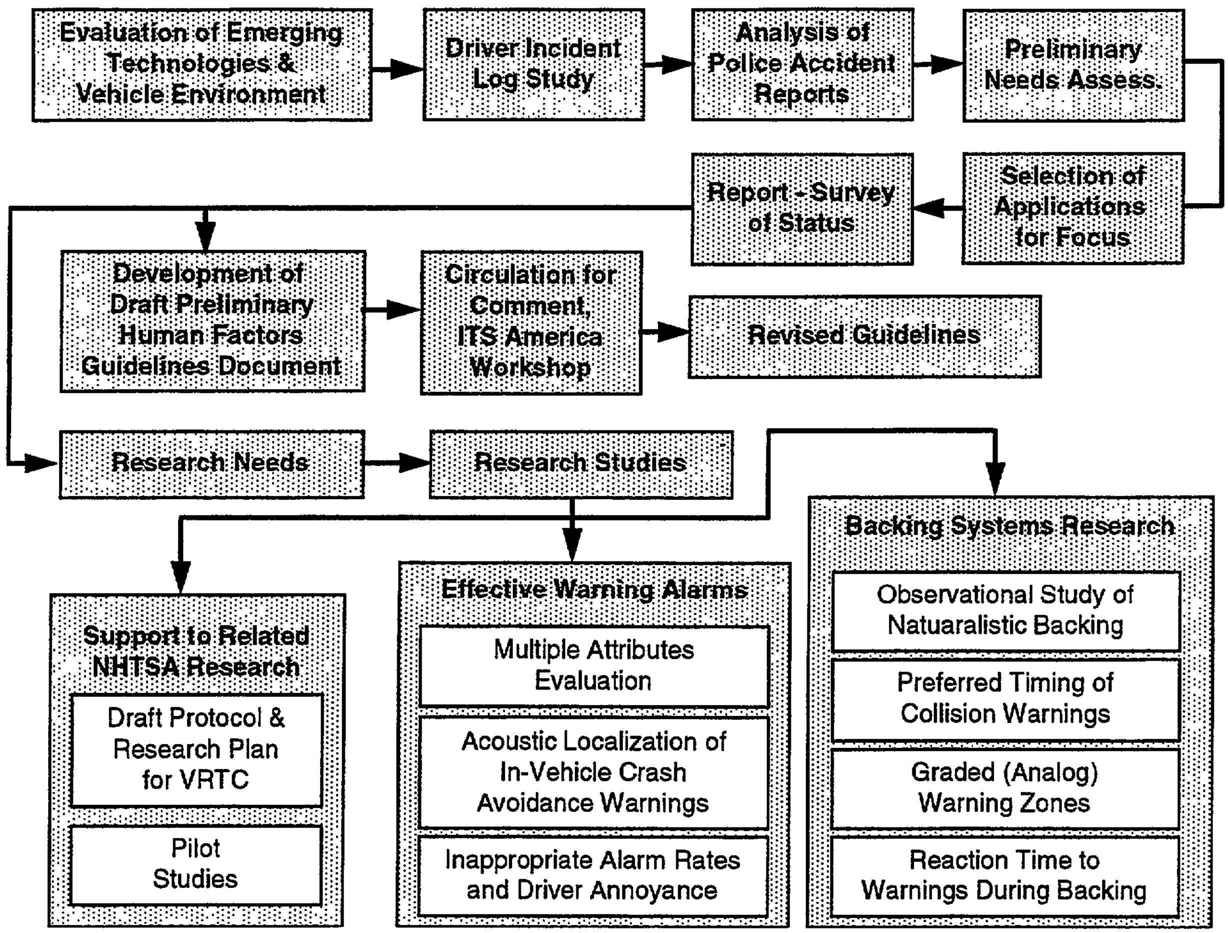


Figure 1. Project Task Flow

The sections that follow briefly describe each of these activities and provide reference to the related technical reports.

3.1 Survey of Human Factors Considerations of In-Vehicle CAW Systems

The initial phase of this project was one of summarizing the state-of-the-art and problem identification. The work is fully documented in COMSIS and Castle Rock (1992). This effort was designed to identify potential in-vehicle warning systems that may be implemented in vehicles by the year 2000. The characteristics of these systems were described in terms of their capabilities, functions, and operational aspects (i.e., the contexts under which each system will be expected to perform and the type of information they will be expected to provide). The likely extent of various warning system components' implementation was explored as well. Potential safety benefits were also considered in light of the various operational contexts. Experts in the field were contacted regarding feasibility and implementation potential. A driver log study was conducted in which drivers kept systematic records of near miss crash situations over a three-month period. Police accident reports were also reviewed to evaluate the potential relationship between various crash types and the appropriateness and effectiveness of various crash avoidance warning systems. This survey served as a background context review for the subsequent task of developing guidelines for component and system design parameters.

A variety of in-vehicle crash avoidance warning systems with the potential to be implemented by the year 2000 were identified. The distinction between vehicle-based warnings and highway-based warnings blurs somewhat, as future systems will carry roadway information into the vehicle, or will combine vehicle-based and external data sources to assess potential hazards. The evaluation focused on autonomous, vehicle-based systems, although for some applications there was limited consideration of additional outside information as well. Seven general categories of devices were considered, based on the hazards they addressed. These included forward obstacle detection (both headway monitoring and obstacle detection), blind-spot monitoring, rear obstacle detection, intersection collision avoidance warning, low road friction, driver impairment (alertness) detection, and rollover warning. These technologies are in various states of development, but all are subject to current research and development. The report provided technical descriptions of technologies and discussed their application and state of development.

In-vehicle crash avoidance warnings are only one of several forthcoming changes to the informational environment of the vehicle. These warnings will have to operate effectively in an environment where other displays compete for attention The report provided an overview of other technologies expected to be present. These include in-vehicle information systems, self-contained navigation systems, dynamic route guidance systems, vision enhancement systems, rear obstacle detection displays, vehicle position monitoring, vehicle status displays, cellular telephones and other communication equipment, and a new generation of entertainment equipment. Familiar types of displays and controls may be supplemented or replaced by such technologies as touch screens, voice activation, soft screens, CRTs, LED displays, head up displays, and synthesized speech.

Because one of the concerns behind this project was the integration of warning systems, both among themselves, and with other systems soon to appear in motor vehicles, the report reviewed safety design parameters for the systems, both generically and specifically for each individual system. The parameters were separated into three groups: Operational, performance, and functionality. Examples of generic operational design parameters were: A large detection range, minimum system processing time, self diagnosis, and the ability to function in a wide range of conditions. Performance parameters included reliability, validity, low maintenance, and accuracy in those cases where a specific parameter is displayed. Functionality parameters included: Comprehension (including self-evident responses after the warning), integration of several warning systems into a master system, and general application to many types of vehicles.

The implementation potential of various warning systems was considered, based on the technical literature and interviews with experts. Feedback from drivers taking part in a log driving study were also considered. Technical issues and limitations exist for virtually all systems, even though some are currently marketed in some form. Some concepts require modification to the vehicle fleet or installation of roadside sensors and communication systems, increasing the cost and difficulty of implementation One factor that emerged as a potential barrier for many applications was manufacturer concern over liability. Consumer interest and acceptance will be a key factor for implementation, but published information on this, for various crash avoidance warnings in particular, was limited. However, the driving log study interviews clearly suggested uneven consumer perceptions of the value of different types of warnings.

The driving log assessment used subject drivers to record information on all near-accident or actual collision incidents over a three month period. The 19 drivers recorded a total of 125 incidents. Lane change incidents were the most frequent category, with intersection and rear-end incidents the next most frequent. The subject reported him or herself to be at fault (singly or jointly) nearly one-third of the time. Overall the driver reported that he or she was "alert" in two-thirds of cases, and "distracted" in only about 13% of the cases. However for those incidents where the driver judged him or herself to be at-fault, distraction was reported in about 40% of the cases. In addition to the data collected from the driving logs, the subjects were interviewed at the conclusion of the study to obtain further information and to explore their attitudes about various possible in-vehicle warnings. The subjects saw blind-spot/lane-change incidents as a major concern and were more favorable to blind spot monitors than any other technology. Intersections were not treated as particularly hazardous, or as a place where technological assistance would be particularly valuable, despite the frequency of intersection incidents in the logs. In addition to blind-spot monitors, warning systems most favored by subjects included headway monitors and driver impairment monitors (although this latter application was seen more as something desirable for the "other" driver, rather than as an aid to the subject).

Approximately 400 recent PAR's were reviewed to assess the relationship of possible collision avoidance warnings to various accident types and the potential safety benefits of various technologies. The review identified the characteristics and common scenarios for eight general categories of collision: rear-end, lane-change/blind-spot, single vehicle run-off-road, head-on, backing, signalized intersection, non-signalized intersection, and drowsy/fatigued driver. Police narratives and diagrams were useful in interpreting situations, even though (as anticipated) useful information about speed and other factors was usually limited. Typically for a given general category of accident, in-vehicle warnings would be potentially helpful for some scenarios and not for others. The estimates were quite general, given not only the limitations of the data but also the need for assumptions about the technologies employed and their effectiveness. For a variety of crash types, it appeared to be more promising to alert the driver to antecedents of crashes (e.g., drowsiness, road friction, etc.) rather than the imminent collision itself. The collision types for which a relatively high proportion of incidents appear at least potentially amenable to direct warnings include rear-end collisions, drowsy-driver accidents, and backing collisions. Collision types related to lane deviations (single vehicle run-off-road, head-on) appear to have lower potential for warnings, although the high fatality rates for these crash types may still yield meaningful safety benefits even if relatively few accidents are affected. Although these accident analyses conducted early in the project have since been superseded by far more extensive crash data studies subsequently performed by NHTSA, the findings were in reasonably good agreement with the later work, and provided an important resource for subsequent project phases.

In summary, a variety of techniques were used to describe the nature of the emerging crash avoidance technologies, identify the vehicle and informational environment in which they will be operating, and clarify behavioral issues related to safety effectiveness and consumer acceptance.

3.2 Development of Crash Avoidance System Guidelines

This effort was designed to outline preliminary human factors guidelines for the design and operation of crash avoidance devices to avoid problems of interface incompatibility with user capabilities, expectations, and needs (Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1996). These guidelines provide both overall guidance for the design of crash avoidance systems in general, as well as specific recommendations for the design of special purpose components. Specific devices include blind spot warning devices, backup warning devices, driver alertness monitoring devices, and headway warning devices. Major topics addressed include: multiple levels of warning, unique imminent crash warning signals, dual modality for imminent crash warnings, non-specificity to sensor or display technology, warning prioritization, compatibility with driver behaviors, warning message content, device status and controls, and minimization of nuisance warnings. The document also contains an extensive reference section that may be valuable for future human factors guidelines developments efforts. A sample page from the guidelines showing the general layout of the information is shown on the next page. Each guideline statement (in boldface) is followed by a short statement providing the rationale and supporting research for the recommendation.

The guidelines document, ***Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices,*** (Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1996) 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. This update of the original report organizes and appends those comments, and cross-references them to the relevant sections of the guidelines.

These guidelines were intended to serve several purposes: 1) to outline the features and functional requirements that any crash avoidance warning device, or collection of devices, should meet in order to perform adequately, regardless of the sensing technology employed; 2) to uncover those areas where additional research is required in order to define optimal criteria; 3) to propose recommendations that will anticipate and avoid many of the problems that can come if warning products are designed in a piecemeal fashion; 4) and to define issues explicitly so that they can be reviewed and debated by specialists within the human factors and ITS communities.

These guidelines served as the foundation for peer debate over crash avoidance warning system design as well as the impetus for the studies performed under the remainder of this contract effort. Specifically, there were two major categories of research concentration performed under the remainder of this project: acoustic alarm characteristics and performance research; and backing systems research. These areas and the individual study results and implications are outlined in the following sections.

2.2 LEVELS OF WARNING.
All warning devices should be capable of generating at least two levels of warning - Immlnent crash avoidance warnings and cautionary crash avoidance warnings.

Research supports a multiple level priority system for alerting situations (Veitengruber, Brucek, and Smith, 19n; Berson et al., 1991). The highest level of warning, termed an “imminent crash avoidance warning in the Guidelines, alerts the operator to a situation which requires an immediate corrections 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, &graded 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.

221 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 locking 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-STD1472D; 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.

Figure 2. Sample page from ***Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices*** (Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1996)

3.3 Research Studies: Acoustic Alarm Characteristics and Performance

Selecting a signal that meets the needs of a generic crash avoidance warning requires the consideration of a number of often conflicting factors. The research performed here was aimed at understanding and working with those factors to define the necessary qualities of an effective signal. Three studies were performed to achieve this result. Initially, an understanding of the attributes that influence the quality of a given signal were analyzed and a set of candidate signal sounds was developed. A second study assessed the ability of several sounds to be useful in a situation where their existence might be coded to provide cues to a driver regarding the nature and location of a given hazard. And lastly, an effort was made to quantify the issue of how many inevitable nuisance alarms from a crash avoidance warning system constitutes too many. These experiments are outlined more fully in the pages that follow. For greater depth, the reader is referred to the reference section at the end of this report and the corresponding technical reports for each study.

Multiple Attributes Evaluation

- ***Full Report - Tan, A, and Lerner, N (1995).*** Multiple Attributes Evaluation of Auditory Warning Signals for In-Vehicle Crash Avoidance Warning Systems. ***Technical report prepared under contract DTNH22-91-C-07004. National Highway Traffic Safety Administration, Washington, DC.***

- ***Background***
One recommendation provided by the Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices (Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1996) is to carefully consider the characteristics of the auditory warning used by each crash avoidance warning device. Due to the number and possible combinations of potential these devices and the range of other in-vehicle indications, specifying an unique and meaningful auditory warning signal for each device, particularly for untrained users, is impractical. Infrequent exposure to such coded messages may also lead to confusion or delays in response. In fact, human factors guidelines recommend restricting the number of coded warning displays, particularly acoustic, to a maximum of around four. The approach in the aviation environment has been to use an attention or master alerting signal supplemented by secondary displays, the latter indicating the nature of the alarm. A similar approach for crash avoidance warning devices in vehicles is suggested. This unique warning signal will be used as the master alerting sound for all crash avoidance warning devices installed a particular vehicle. The type of warning sound appropriate for the master alerting sound was investigated in this experiment (Tan and Lerner, 1995). Secondary information portrayal, indicating direction or type of impending hazard, was investigated in a subsequent study.

- ***Procedure***
This effort was comprised of a three part investigation that evaluated twenty-six different warning sounds as potential candidates for an in-vehicle collision avoidance warning. The three parts of the investigation were as follows:
  1) Expert questionnaire mailing to rate the importance of attributes of auditory warnings
  2) Selection and development of candidate warnings
  3) Multiple Attribute Evaluation (MAE) of candidate warnings

  The third part of the investigation, the MAE, essentially provided the framework for evaluating the candidate warnings using expert opinions (questionnaire results) and end-user acceptability (i.e., through the laboratory experiment). The questionnaire and the selection and development of candidate warnings portions of the investigation provided the expert opinions and the candidate warnings, respectively, that were used in the MAE. The MAE then collected subjects' ratings of each calibrated warning according to the individual rating criteria as the sounds were played in an environment simulating sedan and heavy truck interior noise levels. Randomization, stimulus presentation, and response collection were all performed under computer control.

- ***Design/Variables***
Four categories of warnings were developed to allow an evaluation of both practical and theoretically suitable warnings. A total of 28 stimuli were used. The four categories are as follows:
  1) Existing auditory warnings
  2) Off-the-shelf warning devices
  3) Acoustic warnings developed from guidelines
  4) Voice warnings developed from guidelines

  Thirty-two (32) licensed drivers consisting of two age groups (65+ and 20-40 years) and equal gender mix each participated in two sessions. Subjects were run simultaneously in groups of up to 8 participants, depending on the subject turnout and scheduling.

  Each stimulus was rated according to conspicuity, discriminability, meaning, urgency, response compatibility, experience compatibility, startle effects, orienting response, appropriateness, annoyance, musicality, naturalness, and loudness within the context of the two representative noise conditions.

- ***Findings***

  A mixed design repeated measures analysis of variance was performed for each of the top four expert rated attributes (noticeability, discrimination, meaning, urgency), the annoyance attribute, and the total weighted score for ah 28 sounds. The results showed no main effects for age, gender, background noise, or their interactions. The results of a second analysis did show a main effect for sound type. The acoustic sound type was rated higher than the voice sound type.

  The aircraft low-fuel warning stimulus ranked first in performance on the top four attributes. Other top performers were characterized by relatively high frequency energy with multiple harmonious peaks above a basic tonal component. All had multiple pulses temporally.

  Findings for the voice stimuli were less clear. The voice stimuli were generally less effective than the acoustic sounds. Performance effects were confounded with loudness, making interpretation of effects quite difficult.

- ***Implications***

  Acoustic sounds performed somewhat better than voice stimuli in terms of total rating scores and the low fuel warning should serve as a reasonable candidate for imminent crash warnings. Voice warning implications were far less clear and deserve further study.

Acoustical Localization Of In-Vehicle Crash Avoidance Warnings

- ***Full Report - Tan, A., and Lerner, N. (1996).*** Acoustic Localization of In-Vehicle Crash Avoidance Warnings as a Cue to Hazard Direction***. Technical report prepared under contract DTNH22-91-C-07004. National Highway Traffic Safety Administration, Washington, DC.***

- ***Background***

  The purpose of warning sounds is to alert a driver of potential roadway hazards detected by an in-vehicle crash avoidance warning device. Acoustical localization of the warning sound was investigated as a means of indicating hazard location relative to the vehicle in this study (Tan and Lamer, 1996). The research focused on providing answers to four basic questions:
  - Can acoustical warnings be rapidly and accurately localized in a passenger vehicle environment?
  - What type of warning sound is best for localization in the vehicle?
  - Where should the speakers be located in the vehicle?
  - What speaker combinations could be activated in order to localize warning signals from appropriate directions around the driver?

- ***Procedure***

  Subjects were seated in the driver's seat of a stationary vehicle equipped with 12 audio speakers located at various positions inside the passenger compartment. The speakers allowed 6 warning sound stimuli to be presented from 16 different directions using both single and double activation of speakers (i.e., a pair of speakers could create a virtual direction) for a total of 96 (6 x 16) different conditions.

  During the experiment, the subject's task was to determine from which direction one of the 96 sounds was emanating. The subject input his or her response through a joystick mounted between the front seats. A secondary task required that the subject verbally respond whenever a bridge was encountered along a video-taped route presented on a monitor located on the hood. This ensured that the subject maintained a relatively fixed head position throughout the experiment. It also provided additional workload and prevented the subject from devoting full attention to the localization task. A background noise recording of the interior noise of a vehicle driving on a highway at 55 mph was continuously present as background.

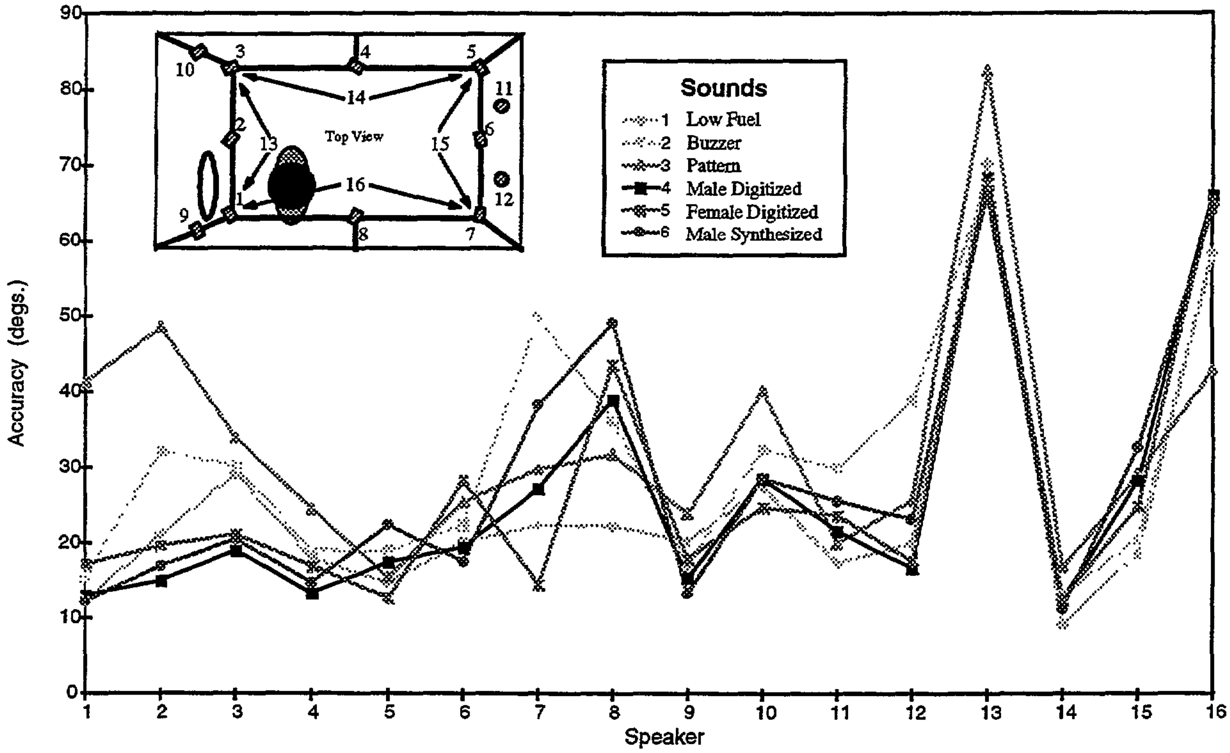
- ***Parameters/Scope***

  Twenty-four subjects participated in the experiment. An equal proportion of male and female participants within each age group was achieved. Each subject underwent 96 unique conditions. Each experimental condition was replicated 3 times for a total of 288 conditions for each subject The factors of the experiment were speaker activation/location (16 levels), sound (3 acoustic warnings and 3 voice warnings), and age (2045 and 65+).

  Response times and perceived direction of the auditory stimulus were recorded during the experiment Response time for localizing the sound was recorded at two points, and was measured from the time the stimulus was first presented. The first measurement point occurred when the joystick was first moved away from the center position (i.e., ***"response time"),*** while the second measurement point occurred when the button on the top of the joystick was pressed once the joystick was positioned in the desired direction (i.e., ***'decision rime").*** The perceived direction of the sound was measured using the x-and y-coordinates input by the subject via the joystick. The coordinates recorded were the values at the time the joystick button was pressed. These coordinates were then transformed into an azimuth heading with the center of origin concentric with the subject's head. A 0" azimuth indicated that the sound was perceived to be heard as originating Tom directly in front of a subject Consequently, each response made by the subject had a localized direction of between 0" and 359". A fourth dependent measure inherent to the coordinate information was the accuracy of each response in terms of the number of degrees the response was away from a correctly localized response. For each stimulus and speaker activation level, the azimuth direction and accuracy of the response was taken as the mean of the azimuth directions and achieved response accuracy across three replications, respectively.

- *Findings*

The chart below suggests that while the majority of responses were not highly accurate (within 15°), most responses were relatively accurate (i.e., within ± 45°), with the exceptions of speakers 13 and 16 (virtual speaker locations for front and left cues respectively). Although for most sounds and speaker locations there were relatively few perceptual reversals, these none-the-less did occur at a sufficient frequency for some speakers to warrant concern.



Sound-by-Speaker Simple-Interaction for Younger Age Group for Accuracy.

- *Implications*

Under the conditions of this experiment, subjects were able to localize the direction of a warning signal with reasonable speed and accuracy. This indicates that directional acoustic cues have the potential to speed driver response to hazards. However, there was meaningful variation in localization performance among alternative warning sounds and speaker locations. Auditory warnings should not be viewed as generally adequate for localized warnings without consideration of the signal and source. Some choices can lead to substantial error. The better-performing sound/speaker combinations of this study led to broadly correct, though imprecise, orientation, with relatively few perceptual reversals. Excluding the poorer speaker/sound combinations, mean errors in localization were about 10° to 20°, though in the vast majority of trials (80-95%), the subject responded within the correct quadrant (i.e., ± 45°). Performance appears promising, though generalizability of the implications is reserved until validation with additional vehicle types and environmental conditions can be confirmed.

Inappropriate Alarm Rates And Driver Annoyance

- ***Full Report - Lerner, N, Dekker, D., Steinberg, G., and Huey, R. (1996.)*** Inappropriate Alarm Rates and Driver Annoyance. ***Technical report prepared under contract DTNH22-9I-C-07004. National Highway Traffic Safety Administration, Washington, DC.***

- ***Background***

  Future in-vehicle crash avoidance warning systems will inevitably deliver inappropriate alarms from time to time, caused for example, by situations where algorithms have correctly identified an object that poses no threat or danger to the driver. The current state of knowledge does not permit an estimate of how many inappropriate alarms users find unacceptable, and how that rate may vary with factors like traffic conditions, the type of signal generated by the system (i.e., tone versus voice), or extended experience with the warning system itself. The purpose of this study (Lerner, Dekker, Steinberg, and Huey, 1996) was a direct comparison of drivers' subjective annoyance towards inappropriate alarms as a function of rate of occurrence and the type of signal generated in naturalistic, on-road driving conditions.

- ***Procedure***

  Test equipment to generate and present signals, and to collect driver response was installed in subjects' own vehicles for a nine week period. Six were presented at random times while the participants engaged in their normal, daily driving routines. In order to simulate future operating conditions where actual alarm warnings will require the driver's attention and reaction, "appropriate" alarms to which the driver had to make a simple motor response, and inappropriate" alarms to which the driver did not have to make any response, were presented. Inappropriate tonal alarms were presented at different frequencies of occurrence. In addition, a voice warning condition was included. Participants made daily and weekly ratings of the degree of annoyance that resulted from the nuisance alarm schedule. All participants were paid for their participation on a base pay plus bonus system; they received a fixed weekly payment for allowing the test equipment to be in their vehicle, and for responding to daily and weekly questionnaires. They also had the opportunity to earn bonus payment for correctly performing the experimental task while driving. All alarms included an audio stimulus. "Real" alarms occurred whenever the audio stimulus was accompanied by a blinking light situated at the passenger side A pillar. "Inappropriate" alarms were defined as the audio stimulus only. For a real alarm sequence, drivers were to press a response button within 20 seconds of alarm initiation. Inappropriate alarms required no response. Drivers had ten seconds in which to check and confirm whether an alarm was a valid one.

  Participants completed a daily questionnaire regarding that day's driving experiences as well as their subjective impressions of the alarms they heard Likert scale ratings were solicited on noticeability and annoyance. Participants were also asked to indicate the kinds of trips they made and the kinds of activities they engaged in while driving. During the weekly visit by an experimenter, participants completed a weekly questionnaire. Questions regarding noticeability and annoyance were asked with regard to the entire week. The participant also rated the acceptability of the inappropriate alarm rate for that week and compared the annoyance of alarms in various driving situations.

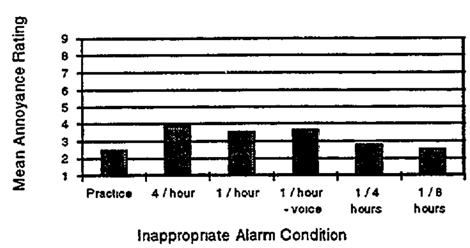
- ***Parameters/Scope***

  Fifteen drivers participated in this study, 8 females and 7 males with ages ranging from 26 to 56 years. Participants were sought who ordinarily drove their vehicles at least eight hours per week. The study lasted nine weeks. Across all experimental conditions, three real alarms were presented at random times during the first eight hours of driving every week. Five inappropriate alarm conditions were superimposed upon this, as follows:

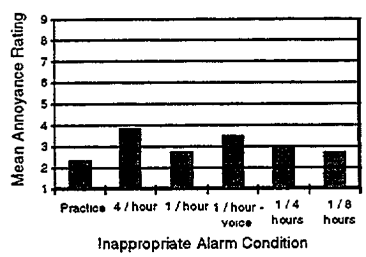
  1) 4 alarms / 1 hour of driving, 1 week duration, tone stimulus;
  2) 1 alarm / 1 hour of driving, 1 week duration, tone stimulus;
  3) 1 alarm / 1 hour of driving, 1 week duration, v oice stimulus;
  4) 1 alarm / 4 hours of driving, 2 week duration, tone stimulus;
  5) 1 alarm / 8 hours of driving, 3 week duration, tone stimulus.

- ***Findings***

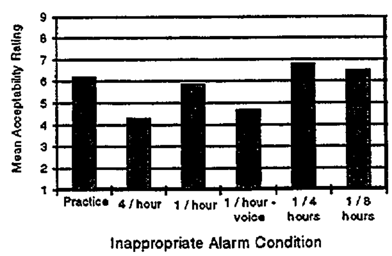
There was no statistically significant effect of the alarm condition on noticeability ratings. for either daily or weekly analyses. Average annoyance ratings generally tended to increase as the frequency of inappropriate alarms increased. Annoyance and unacceptability were greatest for the most frequent alarm condition, averaging four tonal alarms per hour, and for the condition that used a digitized voice message (averaging once per hour). Clearly, alarm frequency and alarm type can have substantial influence on the annoyance response. However, for the tonal alarms, the major effect of alarm frequency appeared to occur between the conditions of 4/hour and 1/hour. The 1/hour rate did not differ significantly from the less dense alarm conditions (1/4 hours, 1/8 hours), although the means for the weekly ratings did show some trend toward this. Participants showed a wide range of annoyance sensitivity.



Average weekly annoyance ratings



Average daily annoyance ratings



Average weekly acceptability ratings

- ***Implications***

Tonal signals of about 75 dB(A) should not occur substantially more often than once per hour of driving time. There were some questions, based on participant comments, about whether 75 dB(A) was always sufficiently loud; we do not know the acceptability of louder, or of driver-adjustable, volumes. At 1/hour, a substantial number of weekly annoyance ratings still exceeded the "tolerable" rating point; given this, plus the fact that true safety-related nuisance alarms may be more annoying, it is probable that 1/hour itself may not be broadly acceptable. However, it is encouraging for intelligent-vehicle applications that the major effect of alarm frequency was seen between 4/hour and 1/hour. Not much influence was seen between 1/4 hours and 1/8 hours, suggesting that drivers may accept warning systems even if nuisance alarms are not extremely rare.

Another implication is that voice messages may lead to substantially greater problems with user acceptance than comparably loud tonal signals. Although only one rate of nuisance alarm (1/hour) was tested with the voice message, annoyance was significantly greater than for the comparable frequency of the tonal signal. In fact, annoyance to the voice alarm was roughly equivalent to the annoyance generated by the tonal signal when it occurred four times as often. The acceptable rate of voice false alarms apparently will be lower than that for other signals, and an average rate of one per hour is clearly not acceptable.

Thus, even under the most sparse nuisance alarm condition tested, nuisance alarms routinely occurred once or twice weekly. Yet both ratings and subjective comments suggested that while some annoyance may have been measurable for those more sparse alarm conditions, it appears rather minimal and acceptable. While future research will have to confirm and refine the findings, the reactions of drivers to extended exposure in their own vehicles suggests that moderate rates of intrusive alarms may be acceptable.

3.4 Research Studies: Backup Warning Systems

Backup warning systems are intended to alert backing drivers to the presence of objects behind their vehicles. These warning devices should be distinguished from parking aids. Parking aids are intended to provide the driver with quantitative information about the distance to known objects (e.g., a loading dock); the driver intentionally monitors the information, to help guide the vehicle more precisely. This is not a safety application A backup warning device, in contrast, must capture the attention of an unalerted driver about the presence of an unexpected and unseen, or misperceived, object behind the vehicle. It must quickly capture the driver's attention and result in a timely vehicle control response.

One difficulty is that backing drivers often intentionally bring their vehicles into close proximity to objects, such as when parallel parking or backing up to a wall or curb. Because the warning system does not "know" if the driver is aware of the object, there is a high potential for frequent nuisance warnings. If a backup warning system is to have good user acceptance, the frequency and level of annoyance of nuisance alarms must be minimized while still maintaining adequate warning time for truly unaware drivers.

Another difficulty is that backing drivers may often be aware of an object behind the vehicle, but they might fail to detect an object that intervenes between them and the recognized object. For example, a driver may see a vehicle eight feet behind him, but not be aware that there is a child only two feet behind him. The driver could receive a warning but misinterpret it to be related to the more distant object. An effective warning system should be able to alert the driver to the existence of the unseen nearer object.

A final concern is that the warning system must be effective over a wide range of vehicle speeds and backing scenarios. Even extremely slow backing speeds, such as during parallel parking, have the potential to injure pedestrians. For more extended backing maneuvers, speeds often may be in excess of 12 mph Different backing scenarios, such as backing out of an angled parking lot space, backing along an extended driveway, or parallel parking, will lead to very different speeds, glance locations, reaction times/stopping distances, and driver expectancies. An effective backup warning system needs to be appropriate to all of these.

The research described in the following sections addresses these concerns with findings relevant to the range of backing tasks. It provides information that characterizes current typical drivers in naturalistic settings and quantifies some of the more salient parameters of driver reaction time and preference/expectancy characteristics for cautionary and imminent crash avoidance warning alarms to be presented to backing drivers. For greater depth, the reader is referred to the reference section at the end of this report and the corresponding technical reports for each study.

Field Measurement of Naturalistic Backing

- ***Full Report - Huey, R, Harpster, J., and Lerner, N. (1995).*** Field Measurement Of Naturalistic Backing Behavior. ***Technical report prepared under contract DTNH22-9l-C-07004. National Highway Traffic Safety Administration, Washington, DC.***

- ***Background***

In order to design an in-vehicle backup warning system, it is essential to understand the behavior of drivers while backing. This includes information about the sequence of events, glance direction, backing velocity, age, task and individual differences. The goal of a backup warning system should not be to force driver behavior modifications, but to understand individual differences and ensure behavioral compatibility. To that end, very little empirical information exists on the nature, sequence, and timing of behaviors that occur under various vehicle backing scenarios. Information about driver behavior will be critical for addressing such issues as the location of warnings, the modality and nature of warnings, the timing of warnings, the parameters that define a hazardous situation, and the need for individually adaptive interfaces for user control. This study (Huey, Harpster, and Lerner, 1995) serves as a data foundation for subsequent studies on performance and user expectations related to backup warnings.

- ***Procedure***

This experiment measured a range of driver behavior variables as drivers made backing maneuvers in their own vehicles under a range of naturalistic backing scenarios. A data collection system was temporarily installed in the participant's vehicle to record measures of driver behavior and vehicle control. The instrumentation suite included video and digital data collection based on a variety of vehicle and external sensor measures. To reduce participant awareness to being observed when backing, a deceptive cover story was used that described the study as an evaluation of vehicle measurement equipment. The ability to record drivers in the normal operation of their own vehicles allowed measurement of "normal," ecologically valid performance, such as typical velocities, distances, and mirror use.

- ***Parameters/Scope***

This experiment considered three factors as independent variables: age, gender, and backing scenario. Twenty-four drivers equally split in age (20-40 and 65+) and gender groups were recruited with useable data obtained from 21 participants. All were licensed drivers from the local area and were screened to eliminate subjects that avoid some types of backing maneuvers. A representative sample of six backing scenarios provided a broad set of situations with varying perceptual and control activity demands upon the driver as follows:

- Extended curved backing to a stop point (2 repetitions)
- Parallel parking against a curb with vehicles fore and aft (2 repetitions)
- Backing out of a perpendicular slot in a parking lot
- Backing out of an angle slot in a parking lot
- Backing to a wall
- Backing into a perpendicular parking slot

Dependent behavioral and vehicle-based measures are outlined below:

- Behavioral Measures: glance direction*, glance duration*, brake useH, accelerator useH, gear selector use*
- Vehicle-based Measures: distance to object, speed/acceleration, time-to-collision (TIC)

*thismeasurewasmarmallyreduoed~mvideoandLinkedtothedatabasefilesfaeachparticipant

Hthis data was collected but deemed too unreliable to be useful

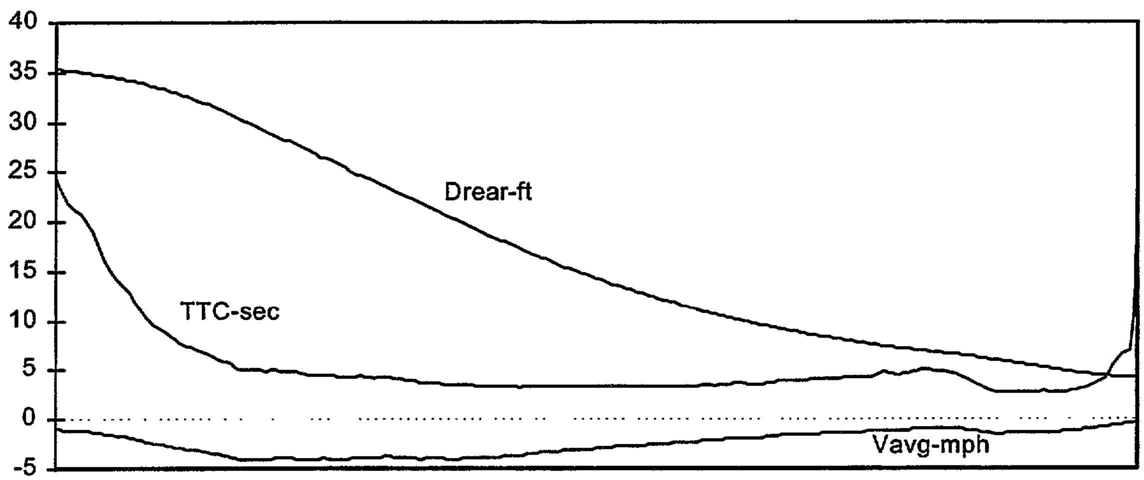
Drivers' glance direction varies greatly with large individual differences within and between tasks. There were large differences between the young and elderly participants. Elderly drivers were far more likely to use their

Glance direction was very similar for males and females both within and across tasks.

There was a wide variation of maximum backing speeds between tasks and participants. On several of the tasks the younger drivers had significantly faster maximum speeds and male drivers had faster maximum backing speeds on 7 of the 8 tasks. On two of the tasks the difference was significant.

TTC at any point of the backing sequence is calculated by assuming constant velocity over the remaining distance to the target. There are large individual differences in minimum TTC, but gender or age were not statistically significant. The data suggest that TTC might be a particularly effective parameter for defining when a warning is necessary, since drivers tend to maintain a relatively stable TTC. Here, drivers never allowed TTC to fall below 1.0 second and it rarely reached the 1.5 to 2.0 second level. However, TTC is not a meaningful measure at the start of a backing maneuver. For example, if an object was only a few inches behind a vehicle, TTC would be infinitely large at the start of the maneuver (since speed is 0), yet it would be desirable to give an immediate warning. Knowing how far drivers back at various times after the start of the maneuver could be useful in defining criteria for warnings as backing begins.

Backing looks rather similar over the first couple of seconds of most of the maneuvers. Most drivers back no more than 2 to 3 feet in the first second and 5 to 8 feet after 2.0 seconds. The similarity among the sites is noteworthy, given the variety of the maneuvers and features. Traveling 3 feet per second is equivalent to a speed of about 2 mph and five feet per second equates to about 3.4 mph. The envelope of distances for the extended curvilinear backing maneuver at one site was roughly 50% broader. We speculate that drivers may have used the accelerator more to initiate travel, rather than just releasing the brake, due to a slight incline.



Example Plot of Velocity-Distance-TTC vs Time (10 sec) during Backing to a Wall

- ***Implications***

Among the implications from the data are the following:

- TTC's below 1.5 or 2.0 seconds suggest a failure to notice an object, and an immediate warning should be triggered if this occurs.
- Prior to vehicle backing, the driver should be warned of objects within 5 feet. Additional cautionary warnings might be appropriate for targets up to 10 feet away.
- The variability of glance locations among drivers and scenarios suggests difficulty in locating visual warnings anywhere that will be universally detectable, implying that they should not be relied on for the primary means of alerting drivers.

Preferred Timing of Collision Warnings

Full Report - Harpster, J., Huey, R, Lerner, N., and Steinberg, G. (1996). Backup Warning Signals: Driver Perception and Response. Technical report prepared under contract DTNH22-91-C-07004, National Highway Traffic Safety Administration, Washington, DC.

- ***Background***

  Previous research on backup warning systems showed that it would be beneficial to have two distinct backup warnings, imminent and cautionary (Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1996). Implementing such an alarm system requires many design decisions including:
  1. When to turn on each type of alarm
  2. How the alarm should vary between cautionary and imminent positions
  3. The alarm acoustic characteristics

  This study (Harpster, Huey, Lerner, and Steinberg, 1996) was designed to examine the first of these questions. This study was designed to serve a dual purpose. In addition to determining the expected warning zone boundaries, it compared judgments under field and laboratory conditions. In the field condition, the subjects were sitting in a car and made judgments as the car approached a target. In the laboratory condition, the subjects viewed a video of the same scene and made their judgments. Both laboratory and field measurements were made since it had been determined that laboratory studies would be required to study some of the more complex acoustic variations, and an estimate of the generalizability of the laboratory judgments to the field situation was needed. This experiment used the same subjects to make warning zone estimates in both field and laboratory conditions. The results of this study will allow us to perform future laboratory studies with a statistical estimate of the confidence of the discriminations.

- ***Procedure***

  Subjective estimates of warning points were compared to reaction time and stopping distance data to determine how people's expectations compare with an engineering analysis of the situation. The imminent and cautionary points were defined as described below.

  > An <u>imminent</u> 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.
  >
  > A <u>cautionary</u> 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.

  In the field part of the study, the subjects were seated in the front seat of the a Nissan Sentra and the experimenter drove the car at an approximately constant speed until the car hit a crash dummy suspended from the ceiling in a parking garage. The subjects looked over their left shoulder to view the target through the back window of the car. When they reached the point where they believed the imminent or cautionary warning (only one per trial) should occur, the subject pushed a button that was recorded by a computer. In the laboratory part of the study, the subjects were seated in a chair and looked over their left shoulder at a video of the same car approaching the same target from the same visual perspective. As in the field study, they pressed a button when they believed that the car was at the imminent or cautionary warning point. The car continued at a relatively constant speed until it hit the crash dummy and did not slow down and stop until after contact was made with the dummy.

- ***Parameters/Scope***

  There were 3 females and 2 males with a mean age of 32. Other independent variables included setting (field and lab), alarm type (imminent and cautionary), and approach speed (2,4,7, and 10 MPH). Each condition was repeated twice for a total of 32 trials per subject. The single dependent variable was the distance to the target when the subject pressed the button. The time until the car reached the target was also calculated, but since the vehicle was moving at a relatively constant speed it was directly related to the distance for any given trial.

- ***Findings***

This study was designed to determine where subjects expect imminent and cautionary warnings when backing toward an object, and to compare these judgments under both field and laboratory conditions. In the field, the mean time for the imminent alarm time was 1.65 seconds across all speeds. The timing of the imminent alarm was fairly constant across the different speeds. On the other hand, the cautionary time in the field study varied greatly for the different speeds from 5.11 seconds for 2 mph to 2.89 seconds for 10 mph. The differences between subjects were large, typically on the order of 4 to 1 for the extreme subjects. While the mean results seem consistent, there was a great deal of variability between the subjects and the results should be used with caution.

The lab study provided a different pattern of results. Both the imminent and cautionary conditions had longer times for the slower speeds (similar to the cautionary field condition). However, there was no replication of the relatively constant times for the imminent field condition. Based on subjective reports that the perception of distance in the lab was 'more difficult' than in the field, a further analysis of the images was performed. This analysis revealed that there was a small difference in image's visual angle between the field and the lab. This difference would account for much of the difference between the lab and the field studies. A correction based on the size of the visual angle makes the cautionary condition very similar between the lab and the field. The imminent condition still has some differences especially at the very slow speeds, but these differences are reduced with this correction.

This study provides estimates of the imminent and cautionary warning zones expected by drivers while backing. The study also examined the differences between field and lab perceptions of these zones. After correcting for visual angle, the lab and field data are consistent with each other with the exception of some relatively minor differences at the 2 mph condition. Additionally, there were very large differences between subjects. This indicates that a backup warning alarm system should possibly have a user adjustment for the threshold of the alarm. Some subjects expected the alarm onset position 3 or 4 times further away than other subjects. It is anticipated that the data from this experiment in combination with the reaction time experiment can be used to determine appropriate warning zones for a backup warning system.

- ***Implications***

This study was designed to determine where subjects expect imminent and cautionary warnings when backing toward an object, and to compare these judgments under both field and laboratory conditions. In the field part of the study, the mean time for the imminent alarm time was 1.65 seconds across all speeds. The timing of the imminent alarm was fairly constant across the different speeds. On the other hand, the cautionary time in the field study varied greatly for the different speeds from 5.11 seconds for 2 mph to 2.89 seconds for 10 mph. This would imply that imminent warnings are predominantly time-based and cautionary warnings are dependent upon the speed.

The differences between subjects were large, typically on the order of 4 to 1 for the extreme subjects. So, while the mean results seem consistent, there was a great deal of variability between the subjects and the results should be used with caution.

The lab part of the study had a different pattern of results. Both the imminent and cautionary conditions had longer times for the slower speeds (similar to the cautionary field condition). However, there was no replication of the relatively constant times for the imminent field condition. Based on subjective reports that the perception of distance in the lab was 'more difficult' than in the field, further analysis of the images was performed. This analysis revealed that there was a small difference in image's visual angle between the field and the lab. This difference accounted for much of the difference between the lab and the field studies. Correction based on the size of the visual angle make the cautionary condition very similar between the lab and the field. The imminent condition still has some differences especially at the very slow speeds, but these differences are reduced with this correction.

Graded (Analog) Warning Zones

- ***Full Report - Harpster, J., Huey, R, Lerner, N., and Steinberg, G. (1996).*** Backup Warning Signals: Driver Perception and Response. ***Technical report prepared under contract DTNH22-91-C-07004. National Highway Traflc Safety Administration, Washington, DC.***

- ***Background***

  A strategy being considered for backup warning alarms is to have a relatively benign cautionary alarm which may or may not change in acoustic characteristics during the interval it is activated. Following the cautionary alarm is a more threatening imminent alarm. A cautionary alarm that varies with the urgency of the situation was hypothesized. The cautionary alarm provides information about the level of the danger as the driver approaches an obstacle. This study examined many variations of cautionary alarms and determined participant's preferences for the different alarm gradation characteristics. Additionally, a measure of annoyance was obtained for several of the alarm conditions.

  Implementing an alarm system that includes a two-level (cautionary and imminent) warning requires that the following questions be addressed:

  1. When to turn on each type of alarm
  2. How the alarm should vary between cautionary and imminent positions
  3. The alarm acoustic characteristics

  This study (Harpster, Huey, Lerner, and Steinberg, 1996) examined questions 2 and 3.

  Although some feature of the warning (e.g. loudness, pitch, pulse rate) may increase in magnitude as the vehicle approaches an object, it is not necessarily the case that a linear increase with distance will provide the best match to the subjective sense of warning urgency. Therefore, this experiment included a comparison of three different functions: one that had a linear relationship to distance, one that increased more rapidly at greater distances, and one that increased more rapidly at short distances.

- ***Procedure***

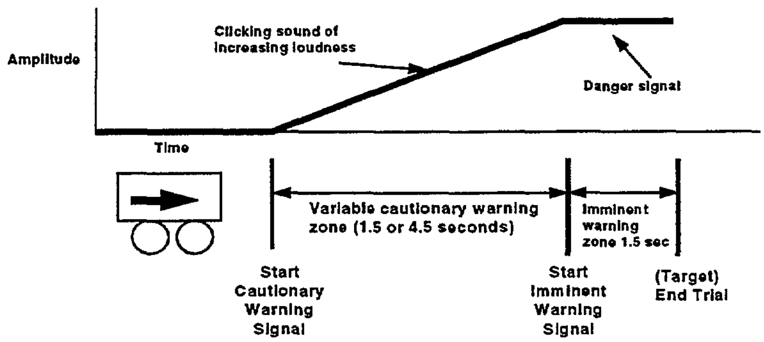
  The study was conducted in a laboratory setting. The experiment attempted to simulate a driver approaching a target and the acoustic properties that would result. The following figure shows an example of the linear variation of the loudness of a sound as a vehicle approaches a target.

  Video tapes were made of a car backing to a life-size dummy suspended from the ceiling of a parking garage. The camera's perspective was from that of a passenger looking over there left shoulder (as with the other studies within this project). One video segment was made for each of four speed conditions (2,4,7, and 10 MPH). These were the same conditions used in the warning zone definition study. A second stimulus tape was made that included the video segments with the various audio feedback conditions dubbed at the appropriate locations in a randomized presentation order.

  During the study sessions, up to 5 subjects were exposed to the audio and video segments simultaneously. They provided subjective ratings related to the appropriateness of the characteristics of the audio feedback with respect to the video segments. Each session was comprised of 112 of these ratings as well as 8 ratings of annoyance for a subset of the stimuli.

Sound Regions

Linear variation of loudness

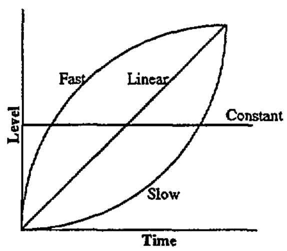


- *Parameters/Scope*

Twenty-four licensed drivers were used in this study. The sample was evenly split between age (<55 and >70) and gender groups. All had normal or corrected-to-normal vision and normal or corrected-to-normal hearing in at least one ear.

The following independent variables were varied during the cautionary alarm period:

1. Cautionary alarm onset time - (4.5 or 1.5 seconds before imminent alarm) These values represent the approximate 5th and 95th percentile from the warning zone definition study.
   Note: the imminent alarm was always started 1.5 seconds before contact with dummy
2. Alarm Pitch - (constant, linear rise, fast rise and slow rise)
3. Loudness - (constant, linear rise, fast rise and slow rise)
4. Pulse Rate - (constant, linear rise, fast rise and slow rise)



The fast rise condition changed from a low to high value very quickly at first and then changed at a slower rate. Conversely the slow rise condition started out changing only small amounts and then changing rapidly near the end of the presentation period.

- *Findings*

As expected, the condition with constant loudness, pulse rate, and pitch was rated the lowest. The condition with the highest rating was fast rise loudness, constant pitch and constant pulse rate. All of the conditions with varying loudness were rated higher than the conditions without loudness variation. The subjects rated the early warnings significantly higher at all speeds. The signals with early warning and loudness variation were rated the most annoying. There were no significant age or gender based differences.

- *Implications*

To indicate distance or time to collision with a cautionary alarm, the loudness should modulated. Linear or fast variation should be used. Subjects prefer early alarm presentations, but this should be traded off against false alarms. The cautionary alarm position could be user adjustable since there were wide individual differences.

Reaction Time to Warnings During Backing

- ***Full Report - Harpster, J., Huey, R, Lerner, N., and Steinberg, G. (1996).*** Backup Warning Signals: Driver Perception and Response***. Technical report prepared under contract DTNH22-91-C-07004. National Highway Traffic Safety Administration, Washington, DC.***

- ***Background***
  The equation used to determine the latest possible time to turn on an alarm to prevent a backing accident can be expressed as follows:

  Alarm onset time = Reaction time + Stopping time

  In order to determine alarm onset times, reasonable estimates for reaction time and stopping time must be known. Stopping and reaction times for cars traveling forward over a range of speeds have been studied extensively. However, reaction times for backing remain to be quantified. Studying backing reaction times presents many challenges. During backing, drivers frequently shift their foot position. There is little debate that the foot position at the time of the alarm has a large impact on the backing reaction time. However, controlling for foot position in a field study is difficult. Forcing subjects to back with their foot in a predefined position may produce unreliable results. This study (Harpster, Huey, Lerner, and Steinberg, 1996) collected data on reaction time and its mitigating factors in a natural setting for use in defining alarm onset times for future warning systems.

- ***Procedure***
  Subjects were asked to back in their natural manner. During their normal backing sequence an alarm was sounded. Their foot position was recorded at the time the alarm was sounded. This allowed collection of the normal range of reaction times that can be expected during normal backing sequences, and permitted the examination of foot position. Knowing the foot position at the time of the alarm, allowed the analysis to be done separately for each foot position. Drivers were alerted to the fact that an alarm would be sounded. Practically, if backup alarms are placed in automobiles, drivers will be alerted that an alarm can go off while backing. Hopefully the alarm will be infrequent, but the driver will not be in a totally unalerted state. Therefore, alerted drivers were deemed to be a reasonable assumption within this study context.

  The subjects drove their own cars on public streets around Silver Spring, Maryland and performed various backing maneuvers. At different points into the backing sequence, the experimenter pressed a button which set off an auditory alarm. The alarm was well in excess of the ambient noise level in the vehicle. The auditory alarm was an aircraft low fuel warning that has been used in several other studies within this project. Upon hearing the alarm, the subject, as fast as safely possible, stopped the vehicle. The reaction time to initiate a brake press as well as the time until the vehicle stopped was measured. Additionally, there were several trials where no alarm was sounded. This prevented the subject from anticipating when the alarm would be sounded.

- ***Parameters/Scope***
  Twelve licensed, active drivers were tested with equal representation between age (20-40 and 70+) and gender groups. Independent variables included backing task (backing to a wall, parallel parking between two cars, and extended curvilinear backing), alarm onset point within the task (early, middle, late and none) in addition to age and gender. No reaction time or stopping distance data was collected on the ‘none’ trials so there was a maximum of 9 data points for each subject, though each visited 12 sites suited to the three backing tasks. Some of the trials were discarded because of equipment failures.

  Dependent variables included reaction time, stopping time, and foot position. Foot position was coded as being on the gas pedal, brake pedal or neither at the time of the alarm.

- ***Findings***

  The major finding was that on average they typical driver was able to stop their vehicle in roughly 1.5 seconds. This is consistent with the imminent warning distance preferences gleaned from previous experiments within this project.

  Interestingly there was very little difference between the elderly and young for stopping time (1.46 seconds for the elderly and 1.48 seconds for the young). The results was obtained mainly because the average speed traveled by the elderly was 2.1 mph and 3.3 for the young. Another difference between the elderly and young was the foot position. The elderly were far more likely to have there foot on the brake than the young. Perhaps the elderly were compensating for slower reaction times by keeping their foot on the break and traveling slower. The total time to stop the vehicle (reaction time + stopping time) was 1.47 seconds and the total distance traveled before the vehicle was stopped (reaction distance + stopping distance) was 4.8 feet. There was very little difference between age groups and genders. The following regression equation can be used to predict stopping distance and time when traveling at different speeds:

  $$\text{Stopping Distance (ft)} = 2.975 * \text{Speed(mph)} - 0.82 \qquad R2 = 0.85$$

  $$\text{Stopping Time (set)} = 0.163 * \text{Speed(mph)} + 1.045 \qquad R2 = 0.40$$

- ***Implications***

  Reaction times and stopping distances were measured under a range of naturalistic backing scenarios. The major finding was that the typical driver was able to stop the vehicle in roughly 1.5 seconds. This is consistent with the imminent warning distance estimated by participants in previous studies.

  Interestingly, there was very little difference related to age. This result was obtained mainly because the average speed for elderly participants was 2.1 mph and 3.3 mph for the younger drivers. Older drivers were also much more likely to have their foot on the brake than the young. This behavior may be seen as a compensatory action by the elderly.

  Stopping times and distances were influenced by the particular backing task the point at which the signal occurred, and the driver's foot position at the signaling point Brake reaction times were very brief if the foot was already on the brake pedal (3 seconds) as opposed to the overall (.66 seconds). Stopping distances were related to vehicle speed and the signaling point. Even under the least favorable conditions, however, stopping distances remained quite short. For the worst case condition, the middle portion of the extended curved backing scenario, the mean total distance was less than 11 feet. Under the more typical, slower backing scenarios, mean total stopping distances were generally under 5 feet, and even 90th percentile distances were under 8 feet.

4.0 RECOMMENDATIONS FOR BACKUP WARNING SYSTEMS

The general features of a recommended backup warning system are listed below. Further detail on these features and the rationale underlying the recommendations follow.

1. The primary warning mode is acoustic; visual displays are a useful supplement

2. There should be multiple levels of warning: imminent crash and cautionary warnings
   - The imminent crash alarm should be a "standard" crash warning, using the "aircraft low fuel warning" signal or other consensus signal with similar alerting properties
   - The cautionary warning should be a distinctly different and less intrusive sound than the imminent crash warning, and should be a pulsed signal with loudness that changes in an analogue ("graded") manner with proximity to the hazard.

3. Criteria for initiating and maintaining a signal depend upon whether the vehicle is in motion or stationary:

Vehicle Status	Triggering Criteria	Warning Duration	Signal Characteristics
In Motion	Time-to-Collision Based	Continuous	Analogue-change until imminent crash signal
Stationary but in Reverse Gear	Distance Based	Transient (acoustic) [visual can remain on]	Fixed signal

Scenarios

There are several different kinds of backing tasks, and several. categories of relationship between the vehicle and the potential collision object, and together these defme the range of scenarios that need to be addressed by a backup warning system. Huey, Harpster, and Lerner (1995) identified six key backing tasks as providing a representative range of backing activities for their investigation of naturalistic backing behavior. These were: parallel parking along a curb; extended backing along a curvilinear drive; backing out of a perpendicular slot in a parking lot; backing out of an angle slot in a parking lot; backing to a wall; and backing into a perpendicular parking slot.

In addition to the various types of backing tasks, the warning scenarios should consider three different relationships of the vehicle and the potential collision object. First is the case where the vehicle is backing toward an object in its path. The second is where the object enters the path of the backing vehicle. The third is where the object is in very close proximity to the rear of the vehicle, prior to the initiation of backing. Whatever criteria are used to trigger warnings should be appropriate for all three of these situations.

Supporting Data

These recommendations are based on data from several experiments, conducted by COMSIS under contract to NHTSA. One was an observational study of naturalistic backing behavior (Huey, Harpster, and Lerner, 1995). Three other experiments are reported in Harpster, Huey, Lerner, and Steinberg, 1996). One was a measurement of driver brake reaction time to signals while backing. Another was a study of people's judgments about the appropriate and desired locations for receiving warnings. The final experiment investigated preferences for various features of graded cautionary warnings.

In addition to these empirical findings, the recommendations made use of guidelines put forth in ***Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices*** (Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1996).

DIFFERENT TRIGGERING CRITERIA FOR "IN MOTION" AND "STATIONARY" SITUATIONS

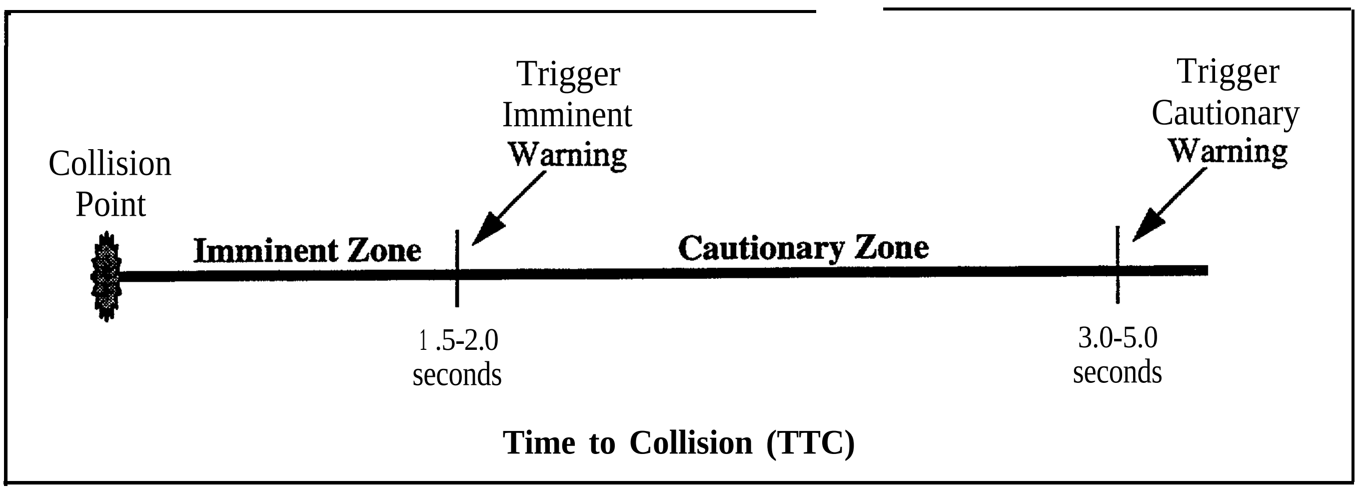
Recommendation:
Triggering algorithms for warnings should be separately considered for the case where the vehicle is already moving in reverse and the case where the vehicle has not yet begun to move in reverse.

Rationale:
Optimal warning algorithms should take into account a number of factors, and the status of these factors is different for the case where the driver already has the vehicle in motion and the case where the driver has not yet begun to move in reverse. These factors are summarized in the table below.

Factor	Vehicle In Motion	Vehicle Stationary
Primary Hazard	Rapidly approaching an object	Unseen object immediately behind vehicle
Relation to Driver Performance	Warning based on evidence of driver error	No evidence of driver error
Response Requirement	Recognize error and bring vehicle to a stop	Prevent driver from initiating movement
Design Considerations	Normal backing behavior, reaction time, stopping distance	Distance traveled per time, visibility considerations
Validity and Annoyance	Minimize inappropriate warning situations	Anticipate high rate of unnecessary warnings

WARNING TRIGGERING CRITERIA: WHILE IN MOTION

Recommendation:
If the vehicle is traveling in reverse, the occurrence of a warning signal, and the level of that warning, should be based on the time-to-collision (TTC) An imminent crash warning should be provided whenever the TTC falls below a critical value, which should be fixed within the range of 1.5 to 2.0 seconds. A cautionary warning should be provided whenever the TTC is above the imminent crash trigger level, but falls below a critical value for the cautionary zone. The trigger level for the cautionary zone could be user-adjustable within the range of 3.0 to 5.0 seconds based on personal preference and individual experience with innappropriate alarm activations.



In-Motion Warning Zone Definition

Rationale:
The TTC is an appropriate basis for a warning because it: (a) serves to discriminate driver error from non-error situations; (b) is a direct measure of hazard proximity; and (c) directly relates to driver response time and stopping distance.

Imminent crash warnings should occur rarely, due to their intrusive nature and the need to maintain a perceived sense of urgency about the signal. The recommended triggering criterion for the imminent crash warning is based on recognizing true driver error conditions, but allowing enough time for the driver to respond by braking. The study of normal backing behavior under a range of backing situations indicated that drivers who were aware of an object behind the vehicle rarely produced TTC's of less than 2.0 seconds, and virtually never produced TTC's below 1 .O second. Short TTC's are therefore a good indicator that the driver has failed to notice the object. While a triggering criterion near 1.0 second would minimize inappropriate crash warnings, the available reaction time and stopping distance would not be adequate for many cases. This time is also less than the TTC that subjects typically indicated they felt was the appropriate point for an imminent crash warning. Values in the 1.5 to 2.0 second range are generally consistent with stopping times and desired warning times, yet are brief enough to exclude most inappropriate (object already seen) warnings for typical drivers.

Criteria for cautionary warnings are less clear, with the relevant driver behaviors being more variable and somewhat related to vehicle speed. The recommended range comes primarily from subjective preference data. Values toward the briefer end of this range may be preferable in reducing the number of cautionary warnings that occur, but would still provide ample warning time to search and react, and would serve to predispose the driver to rapid reaction should the imminent crash warning occur. However, in the experimental studies, many drivers indicated a preference for longer warning times, and since the cautionary warning is less intrusive, this may be tolerable. The possibility of allowing user control of the cautionary warning period recognizes the individual differences in backing performance and warning preference. User adjustment is not recommended for the imminent crash warning, since this should have a fixed meaning that represents the briefest reasonable time for a response.

The data upon which the recommendation is based comes primarily from passenger cars; the appropriateness for other types of vehicles is not known, but in the interim, performance in sport utility vehicles or minivans could likely be assumed to be similar.

WARNING TRIGGERING CRITERIA: PRIOR TO MOTION

Recommendation:
At the moment that a stationary vehicle meets the three criteria of (a) in reverse gear, (b) ignition is on, and (c) there is an object detected within a distance of 8 feet from the vehicle, a cautionary warning should be actuated. The acoustic signal should be transient (e.g., l-2 seconds in duration). If there is also a visual signal, it should remain on.

Rationale:
The purpose of the warning is to prevent the driver from initiating backing if there is an unnoticed object close behind the vehicle. A time-to-collision based warning after the vehicle has initiated motion may not provide adequate time for the driver to react. This situation is a particular concern for the situation where a child is behind the vehicle. Because there will frequently be an object behind a parked vehicle (e.g., another vehicle, a wall, a curb), and there is no way to determine whether the driver is aware of the object, there is a high opportunity for nuisance alarms. For that reason, the less annoying cautionary signal is preferred to an imminent crash signal. A transient acoustic signal is recommended for the same reason, although this may not be critical

The 8 foot distance is recommended based on consideration of observed travel distances and on driver response times to signals. When a signal is given early in the task of backing (but after motion has already been initiated), mean brake reaction times are in the range of 0.4-0.8 seconds, and the mean time before coming to a complete stop is in the range of 1.3- 1.6 seconds. Mean stopping distances are in the range of 5-7 feet. Observations of normal backing maneuvers indicate that most drivers travel no more than 4 feet in the first 1.5 seconds of backing, although a few may travel 6 to 7 feet. Even after 2 seconds, few drivers travel beyond 8 feet. A warning for a stationary vehicle of objects within 8 feet provides conservative protection for the large majority of cases where a driver might not have adequate time to stop once motion has been initiated. The data upon which the recommendation is based comes primarily from passenger cars; the appropriateness for other types of vehicles is not known, but in the interim, performance in sport utility vehicles or minivans could likely be assumed to be similar.

The radius within which to warn a driver in a stationary vehicle might also be influenced by visibility considerations. If there are blind spots which cannot be seen be the driver, it may be desirable to incorporate these within the warning zone. No data on this were used in deriving the recommendation, and visibility regions may be highly vehicle-specific.

ACOUSTIC WARNING ATTRIBUTES

Imminent Crash Warning -- Recommendation:
The imminent crash warning for backing situations should use the same signal as that for other imminent crash warning situations. In the absence of an industry standard or consensus, an "aircraft low fuel warning" alarm is recommended.

Cautionary Warning -- Recommendation:
The cautionary warning should consist of a rapidly pulsed signal that increases in amplitude as the vehicle approaches the target object. The sound should be distinctly different from the imminent crash warning signal. The initial volume should be readily detectable by drivers under the anticipated range of operational backing and environmental noise conditions, and the final volume should not exceed the level of the imminent crash warning. Signal intensity should be linearly related to object proximity.

Rationale:
An acoustic signal is preferable to a voice signal for this application because: (a) unnecessary warnings are expected and voice messages appear more annoying as intrusions while driving (Lerner, Dekker, Steinberg, and Huey, 1996); and (b) additional information available from a voice message is unnecessary, since the act of backing defines the nature of the warned-about hazard. ***Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices*** recommended that a single "imminent crash" warning signal be used for all crash avoidance applications. Tan and Lerner (1995) identified several reasonable candidates, with the "aircraft low fuel warning" as the strongest.

Graded cautionary backup warnings were preferred by subjects to fixed warnings in research studies. They are also desirable on the grounds that they can discriminate nearer from farther hazards so that the driver can interpret the object being warned about, they provide an indication of the rapidity of approach, and they provide a distinct signal change should a new object suddenly enter the area behind the vehicle. Signal intensity (loudness) was recommended as the preferred signal dimension to vary, because subjects found this to be the most consistent with the subjective sense of impending collision. Adding additional dimensions of fundamental frequency (pitch) or pulse rate provided no additional benefit. While loudness appears to be the preferred dimension based on information to this point, the recommendation should be seen as tentative, since the research did not evaluate signals under the range of expected acoustic background conditions (e.g., stereo system on) or under actual backing performance. The recommendation for a linear function (linear relationship of sound level to target proximity) stems from comparisons of linear, positively accelerated, and negatively accelerated functions. This variable did not have a large effect, and none were significantly better than the linear function, which is the most simple and understandable.

No specific pulse rate for the cautionary signal was recommended in the absence of formal evaluations, but it should be rapid enough so that changes in the signal are immediately apparent and a sense of rate-of-change is perceptible. A pulse rate on the order of 15 Hz may be a reasonable choice.

VISUAL WARNING ATTRIBUTES

Recommendation:
A visual warning signal may be used to supplement the imminent crash and acoustic warnings, but should not be used in place of them. A visual imminent crash warning should present a flashing red signal; a visual cautionary display should be a steady amber or red signal. The cautionary signal may be graded on the color dimension of amber to red, but should not vary in brightness or flash rate. Green should not be used. Alpha-numeric displays should not be used. If a visual display is used, it should be conspicuous and not require intentional monitoring by the driver. Multiple display locations are recommended. For automobiles, a display should be visible when looking over the right shoulder. Backup visual warning displays should not be located on the vehicle dashboard.

Rationale:
Visual displays are not recommended as the primary warning mode, both because acoustic warnings are generally more effective for crash warning situations (as indicated in ***Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices)*** and because a study of naturalistic backing behavior found that looking was directed to so many diverse locations that it was difficult to find appropriate locations for such a display. Recommendations for display colors ***also*** come from the ***Preliminary Guidelines.*** If a visual warning is graded to match hazard proximity, neither flash rate nor brightness would be appropriate dimensions, which is why color was suggested. Flash rate is inappropriate because of the requirements that only the imminent crash warning flash. Brightness is impractical because the apparent brightness will vary with light conditions, and because the effective range between a minimum detectable brightness during daylight glare, and the maximum brightness for other conditions, may not permit a highly perceptible coding range.

If visual displays are used, the appropriate site(s) for locating them become an issue. The naturalistic backing study found a great deal of variability between different backing situations, as well as between drivers, in terms of where looks were directed. No single location seemed appropriate for all situations, although glancing over the right shoulder was the most common glance direction for these passenger car drivers. For this reason, multiple locations seem most satisfactory from a safety standpoint. Visual displays may be mounted on or near vehicle mirrors, but this would still be ineffective for the most common glance location in a passenger car. The problem may be less difficult for other types of vehicles (e.g., vans), where there is no direct outside visibility anywhere behind the driver. The recommendation to avoid placement of the display on the dashboard comes from the findings of the naturalistic backing study. Drivers virtually never looked at this location, and it was often not within the effective cone of vision of other common glance locations while backing. If a dashboard display draws the backing driver's attention, it may disrupt normal visual search and vehicle control.

5.0 REFERENCES

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