CHAPTER 4

PRELIMINARY MINIMUM FUNCTIONAL REQUIREMENTS AND RECOMMENDATIONS

TABLE OF CONTENTS

List of Tables

List of Figures

4 PRELIMINARY MINIMUM FUNCTIONAL REQUIREMENTS AND RECOMMENDATIONS

4.1 Introduction and Methodology

The project is to focus on collisions between the front of a host vehicle and the rear end of another vehicle. These requirements are a set of development goals for what a FCW system should do; they do not specify how to achieve these goals. There is no claim that these requirements can be met with currently available technology. Furthermore, it should be stressed at this point that the current project represents CAMP's best efforts at developing preliminary functional requirements for a FCW system. Further evaluation of these requirements under in-traffic, operational field test, and vehicle-level testing conditions will undoubtedly provide additional information for refining these requirements.

No single crash countermeasure can be effective in preventing or mitigating all types of crashes. The variety of crash types, which occur, and the numerous causal factors involved, make it necessary to focus individual countermeasure systems on particular categories of collisions. FCW systems focus on helping the driver avoid or reduce the severity of rear-end crashes with other vehicles.

The primary objective of this chapter is to propose requirements that result in systems that meet driver expectations regarding a FCW system. These requirements result from the best efforts of the Program participants to reflect those expectations. These requirements were used to development a set of test procedures for FCW systems. The process used to develop these requirements involved the following, sometime simultaneous, areas of work (Figure 4-1):

- Development of an assumed set of customer expectations for a FCW system.
- Definition of the functional requirements for a hypothetical ideal system.
- Adjustment of the requirements based upon expert opinion on technical feasibility.
- Accommodating human factors and driver behavior considerations.
- Comparison of the suggested requirements with those developed in other projects by other organizations.
- Computer-based modeling of performance.
- Adjustment of the requirements based upon expert opinion of the consumer perspective.

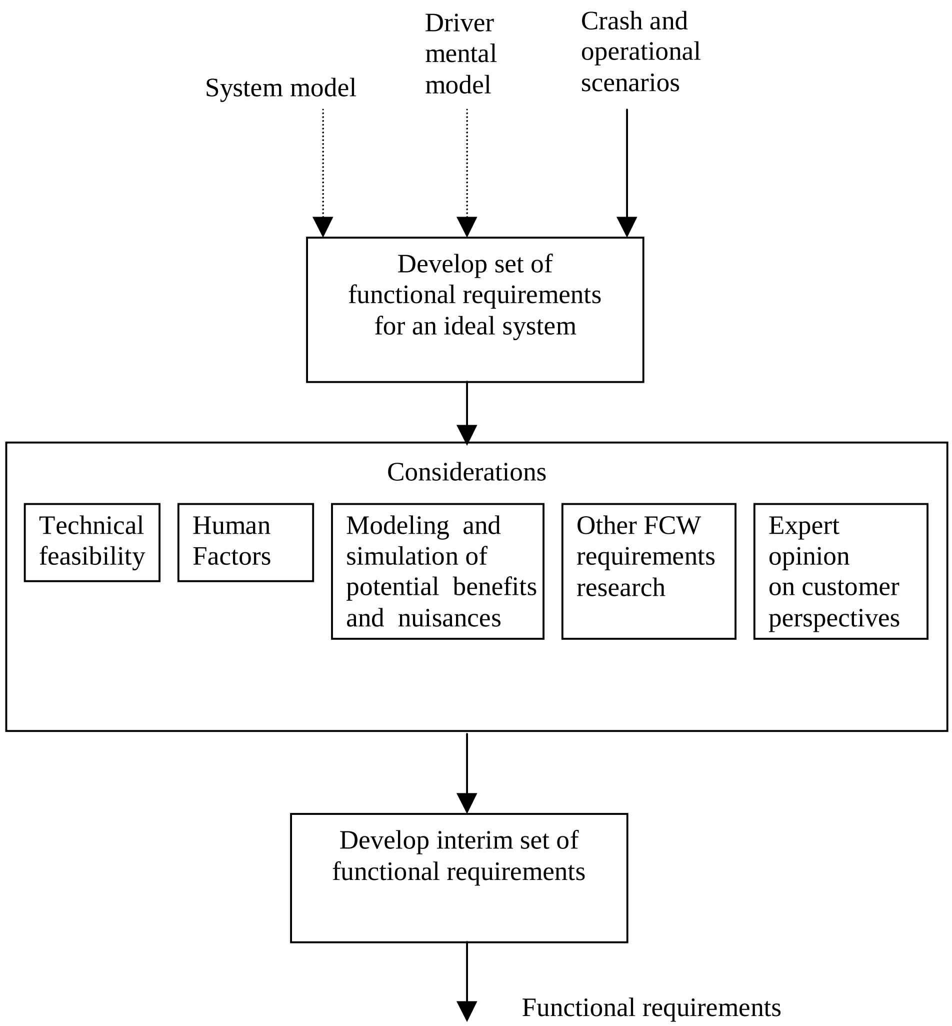


Figure 4-1 FCW System Requirements Development Process

The requirements include:

- Driver-vehicle interface functional requirements, including crash alert timing and crash alert modality requirements.
- The dimensions of the *Alert Zone*, defined as the region in space ahead of the equipped vehicle where alerts are required if the obstacle meets other criteria such as relative speed and distance from the host vehicle.
- Maximum levels for how often out-of-path nuisance alerts are allowed to occur.
- Maximum levels for how often in-path nuisance alerts are allowed to occur.
- Other FCW performance requirements.

The remainder of this chapter is divided into six sections. Section 4.2 describes the driver-vehicle interface requirements, and focuses on defining the crash alert timing and crash alert modality. Section 4.3 describes the Alert Zone shape and boundaries. Section 4.4 reviews the Crash Scenarios from Chapter 2 and presents the preliminary minimum functional requirements derived from each one. Section 4.5 describes the nuisance alerts, and Section 0 presents the Operational Scenarios requirements. Section 4.7 tabulates the requirements developed in the previous sections.

The reader should be reminded at this point that these requirements are considered *preliminary* functional requirements. Throughout these requirements, the words "*shall*" and "*should*" are often used, and are intended to communicate different levels of importance with respect to compliance with these preliminary requirements. The word "shall" is meant to indicate the proposed minimum preliminary requirement must be met, and there shall be no deviation from this requirement. The word "should" is meant to indicate the proposed preliminary requirement should be met, but the level of knowledge does not merit preventing (or not allowing) deviation from this requirement. In many of these "should" cases, it is not the case that the preliminary minimum requirement is in a sense optional, but rather that the range or range of values proposed for the preliminary requirements lacks a solid empirical basis at this point to allow no deviation from this requirement.

4.2 Driver-Vehicle Interface Functional Requirements

This portion of the document describes the preliminary minimum functional requirements for a FCW system driver interface, with the primary focus on requirements for FCW system crash alerts (Sections 4.2.1 to 4.2.4). More specifically, these requirements are primarily focused on <u>when</u> to present crash alerts to drivers (i.e., the crash alert timing) and <u>how</u> to present crash alerts to drivers (i.e., visual, auditory, and/or haptic alerts). It should be stressed that how to present crash alert information is intimately related to when this information is presented. In general, as the likelihood of an impending collision if no evasive vehicle control action (e.g., braking) is taken increases, the need for the crash alert to more aggressively warn (and potentially annoy) the driver increases. Furthermore, as the crash alert becomes more aggressive (i.e., occurs later or at a closer distance), the need for reliable/accurate crash alert information increases.

Requirements for FCW system information not directly related to crash alerts (i.e., system malfunction, system limitation condition) are discussed in a more general fashion in Section 4.2.5. Section 4.2.8 briefly discusses how the FCW system driver interface should be integrated with non-FCW systems (e.g., adaptive cruise control). Overall, these requirements are intended to address the need for a clear and relevant set of human factors requirements for FCW systems. All cited references are alphabetically listed in Section 4.8

These minimum driver interface requirements, as well as interface recommendations, are based primarily on data from the four CAMP human factors studies described in detail in Chapter 3. (This is particularly true for the specific requirements focused on crash alert timing and crash alert modality discussed in Sections 4.2.1 through 4.2.4). These CAMP Human Factors data were gathered under highly valid, controlled, realistic conditions involving a wide range of drivers braking to a realistic crash threat.

These preliminary functional requirements have been formulated through reviews and analyses of the best-available data, and in this sense, should be considered state-of-the-art. Given a manufacturer has decided to implement a FCW system, these requirements should be used as a tool for designing a FCW system which allows the driver to take full advantage of FCW system technology for reducing the frequency and severity of rear-end crashes.

Each section presents a definition of the requirement, discussion of the supporting rationale for the requirement, followed by the requirement itself. The requirement is enclosed in a box. When possible, a quantitative requirement is presented either as a point value or as a range. If this was not possible, the requirement is presented qualitatively in more general terms. In addition, there were cases where the level of available data obtained in the four CAMP human factors studies discussed in Chapter 3 suggested a driver interface recommendation (i.e., an “optimum” interface design) which exceeded the minimum requirement, but the level of available data to support this recommendation was not deemed sufficient for a minimum requirement. These “CAMP recommended approaches” are indicated in italicized font in the bottom of the requirement box.

4.2.1 Crash Alert

The *crash alert* refers to a mechanism by which the driver is informed via some type of alert or alerts (e.g., a tone and visual warning) of the likelihood of an impending collision if no evasive vehicle control action (e.g., braking or steering) is taken. Irrespective of the form or modality of the crash alert, this information is of high priority and must be clearly conveyed to the driver in a timely and effective manner. The preliminary requirements for the number of crash alert stages, timing, and the method of presenting these alerts are discussed in Sections 4.2.2, 4.2.3, and 4.2.4, respectively.

At this point it should be mentioned that the remainder of this driver-interface requirements section addresses crash alerts in the situation when the driver is in immediate danger of impacting the lead vehicle, rather than tailgating situations in which the driver is following closely but is not expected to impact the lead vehicle in the immediate future. The philosophy taken in these minimum functional requirements is that although “closing” crash alerts are required, a *tailgating advisory* would be optional. (It should be noted, that Wilson, Butler, McGehee, and Dingus (1997) also do not consider such an advisory to be a minimum requirement for a FCW system.)

In terms of the preliminary functional requirements for a FCW system driver interface incorporating a tailgating advisory, the following general comments can be made. First, a warning used for a closing crash alert should not be presented in tailgating situations, since the driver should only be issued a closing alert when a collision is likely to occur if evasive vehicle control action (e.g., braking) is not taken *immediately* (see Section 4.2.2). Second, due to the anticipated annoyance factor associated with a tailgating advisory, the criterion for this advisory should be adjustable with a separate control from the crash alerts, and this control should include an “off” position. Third, for similar reasons, the tailgating advisory should be presented to the driver via the visual modality only rather than employing either the auditory or haptic modalities.

4.2.2 What Should be the Number of Crash Alerts Stages?

Most systems described in the literature (particularly production systems) use a 2-stage FCW system alert scheme (Eaton VORAD, 1996; Frontier, 1995; International Standards Organization, 1996a; Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1996b; NHTSA, 1996; Watanabe, Kishimoto, Hayafune, Yamada, and Maede, 1995). The first, relatively less urgent, stage is referred to as a “cautionary” alert. This alert is presented when a collision is likely to occur if evasive vehicle control action (e.g., braking) is not taken soon. The second, relatively more urgent, stage is referred to as an “imminent” alert. This alert is presented when a collision is likely to occur if evasive vehicle control action (e.g., braking) is not taken immediately. Irrespective of the nature of the adjustability of the crash alert timing, the cautionary crash alert should generally occur at a greater distance than the imminent crash alert. It should be noted that some FCW systems proposed have included more than two stages of alert (Graham et al., in press; Landau, 1995; McGehee et al., 1993; Nakajima, Satoh, Kikuchi, Manakkal, Igarashi, and Chiang, 1996).

One potential advantage of a 2-stage alert over a 1-stage crash alert approach is that the driver is provided the opportunity (via a cautionary alert) to avoid a situation where evasive vehicle control action (e.g., braking) must be taken immediately. However, one potential large disadvantage of a 2-stage crash alert approach is that drivers may find a certain percentage of cautionary alerts annoying, whereas they may rarely find imminent alerts annoying (discussed further below). For this reason, consumer acceptance could ultimately dictate a 1-stage warning scheme. It should also be noted that with the exception of a series of studies conducted at the TNO Human Factors Research Institute (Horst, 1990; Janssen and Nilsson, 1990; Janssen and Thomas, 1994; Nilsson et al., 1991), 1-stage warning schemes have received relatively little attention in human factors research.

The CAMP Task 4 driver interface studies focused exclusively on examining 1-stage warnings. The rationale for evaluating 1-stage rather than multiple-stage (e.g., a 2-stage cautionary alert/imminent alert approach) crash alert types was based in part on results from CAMP Study 1. These results suggest that the 50th percentile required deceleration value observed in that study under “hard braking” driver instructions appeared very promising as an appropriate (not too early/not too late) single point estimate of the assumed driver braking onset range (or distance) for crash alert timing purposes. The required deceleration measure was defined as the constant deceleration level required for the driver to avoid the crash at braking onset. This measure was calculated by using the current speeds of the driver’s vehicle and the lead vehicle, and assuming the lead vehicle continued to decelerate at the prevailing deceleration value (i.e., at the current “constant” rate of slowing). Put in another way, it was felt this required deceleration-based estimate would ensure that for a high percentage of drivers that the onset of braking in response to a crash alert would:

- Occur at a closer range than their braking onset range during “aggressive” normal braking.

- Allow sufficient range for the driver to avoid the crash.

The required deceleration data from CAMP Study 1 was modeled (explained further below) and provided the basis for assumptions made about driver braking onset range. It is also important to note that these required deceleration values were relatively uninfluenced by driver age or gender in CAMP Study 1, which is a desirable finding from a production implementation perspective. Furthermore, it was felt and later observed that the low percentage of drivers not accommodated by (2) above (allowing sufficient range for the driver to avoid the crash) would brake harder in response to a crash alert (i.e., they were *capable* of braking harder) than what was observed during their preferred “last-second” hard braking judgment in CAMP Study 1.

Additional reasons for employing a 1-stage rather than multiple-stage crash alert approach were the following. First, with respect to the compatibility of a FCW system integrated with an Adaptive Cruise Control (or ACC) system, a 1-stage alert is more consistent with the 1-stage ACC system driver alerts being considered (e.g., one possible ACC alert is to warn the driver if they have exceeded the maximum braking deceleration authority of the ACC system). Early production implementations of FCW systems are likely to be integrated with ACC. Since an ACC system alert may be largely consistent with the meaning intended by a FCW system alert (i.e., a collision may occur unless evasive control action is taken), the use of a 1-stage alert for both ACC and FCW systems may be promising from a customer education, simple “mental model” perspective.

Second, with respect to a “stand-alone” FCW system, a 1-stage alert is much more simple and elegant from a customer education (”mental model”) and production implementation perspective. For example, the driver only has to interpret the meaning of one (versus more than one) alert. In addition, if the alert timing (or criterion) is under driver control, the effect of the driver adjusting a 1-stage alert criterion is relatively straightforward. In a multiple-stage alert scheme, the effect of such an adjustment is less straightforward. For example, do adjustments effect multiple alert stages? Are adjustments permitted for the most imminent alert?

Third, a 1-stage alert provides a potential means of reducing in-path (“too early”) nuisance alerts and out-of-path nuisance alerts relative to the first stage of a 2-stage (or multiple-stage) crash alert approach. In this case, it is assumed the first stage of a 2-stage (or multiple-stage) alert approach would be more conservative (i.e., the alert would occur earlier or at a farther range to the vehicle ahead) than a 1-stage alert. These increases in nuisance alerts could reduce system effectiveness (e.g., drivers’ brake RTs to the alert could increase), system usage in FCW-equipped vehicles (i.e., drivers may turn the system off), and negatively impact driver acceptance of FCW systems. On the other hand, it could be argued that, providing these “first stage” nuisance alert concerns could be addressed, a properly designed 2-stage approach might give the driver an earlier opportunity to avoid “near misses” and situations where evasive control action must be taken immediately, as well as respond earlier under poor traction or poor atmospheric conditions. However, these potential benefits of a 2-stage crash alert approach may also be able to be attained with a 1-stage crash alert with an adjustable crash alert timing feature.

Fourth, based on CAMP experiences during pilot testing attempting to sequence the 1-stage alert and the "bail-out" alert (i.e., the alert was used to signal the passenger-experimenter to take over and begin braking), which can be thought of as but one example of a 2-stage alert, a concern was identified that the extremely short time lag between the two crash alerts might render the 2-stage alert distinction meaningless and potentially confusing for the driver. Hence, this raises the possibility that under the wide range of vehicle-to-vehicle kinematic scenarios likely to trigger crash alerts examined in these CAMP studies, a 2-stage alert may be more confusing than helpful for the driver. More generally, rapid sequencing of multi-stage alerts are more likely to occur under conditions when the driver's vehicle is rapidly closing in on the lead vehicle such that the difference in speeds between these two vehicles (i.e., the delta velocity) is building up rapidly. (Conversely, slower sequencing of multi-stage alerts are less likely to occur under conditions when the driver's vehicle is slowly closing in on the lead vehicle such that the difference in speeds between these two vehicles (i.e., the delta velocity) is building up slowly.) Examples of conditions under which rapid sequencing may occur include when the driver of an FCW-equipped vehicle is approaching a stopped or braking lead vehicle, as well as under various cut-in/merge and lane change situations. It should be stressed that the distinction between the moments at which "soon" and "immediate" evasive control action are required, associated with cautionary and imminent crash alerts, respectively, is solely dependent on a particular crash alert timing approach. If this distinction is relatively minor under most vehicle-to-vehicle kinematic conditions (causing a rapid, potentially confusing sequencing of these alerts), particularly if those conditions are relatively more serious in nature, then the merits of a 2-stage alert are questionable. It is worth noting that the previous recommendation made by Lerner et al. (1996) for 2-stage automotive crash alerts was based on research examining aircraft alerting systems, which may have very different alert time-courses (e.g., slower-developing time-courses) relative to automotive crash alert systems.

Indeed, one could argue that multiple-stage (e.g., 2-stage) alerts should be avoided unless the advantages of using such alerts outweigh the disadvantages of such alerts. As discussed above, potential disadvantages of multiple-stage alerts relative to a 1-stage alert include potential non-compatibility with ACC system driver alerts, increases in system complexity from a customer education (driver mental model) perspective, increases in system complexity from a production implementation perspective (e.g., added controls and displays), and increases in nuisance alerts which could reduce system effectiveness.

For these reasons, a 1-stage crash alert approach is recommended. However, multiple-stage crash alerts are not prevented by the following minimum requirement, in part because such approaches were not evaluated in the CAMP human factors studies for the reasons described above. However, if a multiple-stage crash alert is implemented, additional stages shall not reduce the effectiveness of the most imminent alert <u>and</u> all CAMP minimum requirements must be met for both a fixed FCW system and for the minimum (latest, closest) setting for a FCW system which provides crash alert timing adjustability.

Suggested possible approaches for a multiple-stage crash alert which are most likely to satisfy this minimum requirement are presented in the last paragraph of Section 4.2.4

The FCW system shall have at least a 1-stage FCW crash alert.

The FCW system may have multiple-stage (e.g., 2-Stage) FCW crash alerts provided additional stages do not reduce the effectiveness of the most imminent alert <u>and</u> all CAMP minimum requirements are met for both a fixed FCW system and for the minimum (latest, closest) setting for a FCW system which provides crash alert timing adjustability.

<u>Recommended Approach</u>: The FCW system should have a one-stage crash alert. **(1)**

4.2.3 When Should Crash Alert Information be Presented to the Driver?

4.2.3.1 Crash Alert Timing and Crash Alert Timing Adjustability

On the most general level, the position taken in these minimum functional requirements is that the FCW system should not be allowed to be turned off by the driver inadvertently or otherwise, due to the safety-related aspects of this system. Given this position, it should be stressed that great care must be taken in mimimizing both in-path and out-of-path nuisance alerts, since the driver will not have the option to turn the system off. (It should be noted that subsequent technology experience with FCW systems might suggest allowing the driver the capability of turning the system off to reduce nuisance alerts, in which case the FCW system should default to a system "on" state at the beginning of an ignition cycle.)

The *crash alert timing* (or crash alert criterion) for a FCW system refers to the necessary underlying conditions for triggering the onset of crash alerts. The *crash alert timing adjustability* for a FCW system refers to a mechanism by which the driver can adjust the timing setting for triggering crash alerts. The following CAMP requirements address the minimum alert timing setting (i.e., the latest, closest setting) for a FCW system which is adjustable by the driver, as well as the alert timing for a fixed, non-adjustable FCW system. These requirements do not address the maximum (i.e., the earliest, farthest) alert setting for a FCW system with an adjustable crash alert timing, and leave these maximum settings unconstrained. The implicit assumption is that if a driver with an adjustable FCW system perceives the timing of crash alert onset is "too early" (i.e., the nuisance alert rate is unacceptable for the driver), the driver will adjust the alert timing toward a later, closer setting. The following minimum requirement places a lower cut-off (or bound) on the latest, closest setting for an adjustable FCW system. Hence, the driver is not allowed to adjust the crash alert timing below the minimum level specified below.

These timing requirements must be met for the conditions in the objective test procedures discussed in Chapter 5 of this report. These timing requirements may not be appropriate for conditions outside the bounds of vehicle-to-vehicle kinematic conditions examined in the CAMP human factors studies and the objective test procedures discussed in Chapter 5.

Under this minimum requirement, the onset of the FCW crash alert must occur anywhere within an *acceptable crash alert timing zone*, where this zone is defined by “too early” and “too late” onset range cut-offs (or bounds). This crash alert timing zone concept is illustrated in Figure 4-1 for the case when a driver of a FCW-equipped vehicle is approaching a parked vehicle. (The case in which the lead vehicle is stationary is shown here for illustrative purposes, but the reader should note the same concept applies to cases in which the lead vehicle is moving.) It should be stressed that this requirement does not specify that any particular crash alert timing approach be employed (e.g., the crash alert timing approach employed in the three CAMP driver interface studies), but instead, simply requires that whatever crash alert timing approach is used yield performance consistent with these minimum timing requirements. The rationale for these “too late” onset and “too early” onset range cut-offs will now be discussed in detail.

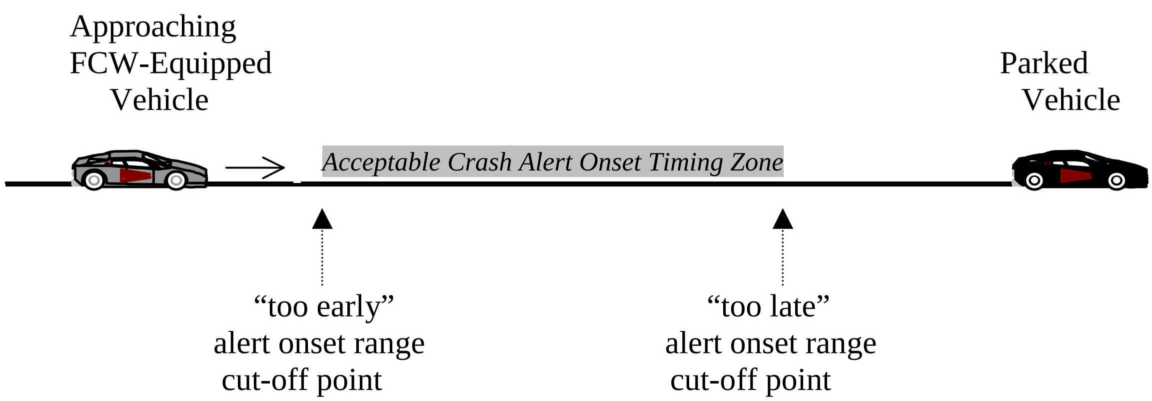


Figure 4-2 Concept of the Acceptable Crash Alert Onset Timing Zone (The case in which the lead vehicle is parked is shown for illustrative purposes.)

The four human factors studies described in Chapter 3 of this report (as well as the modeling of the data gathered in Study 1, which is reported in Appendix A20) provided the underlying rationale for establishing the acceptable crash alert onset timing zone. In general, the “too early” onset range cut-off is more focused on driver preference considerations (including in-path nuisance alerts) for crash alert timing under various vehicle-to-vehicle kinematic situations. In contrast, the “too late” onset range cut-off is more focused on driver braking capability (rather than driver preference), and was derived from examining drivers’ actual braking under various vehicle-to-vehicle kinematic situations. It should be stressed here that driver capability can be contrasted with the maximum braking capability of the vehicle (i.e., the braking capability yielded by a test driver). The human factors work central to developing this crash alert onset timing zone will now be briefly described. The reader interested in a more detailed description of this work is referred to Chapter 3 of this report, as well as to Appendix A20, which describes the process used for modeling hard braking data obtained in the first human factors study (CAMP Study 1) for crash alert timing purposes.

In developing a crash alert timing approach for a FCW system, two fundamental driver behavior parameters have to be considered. The first parameter is the driver deceleration (or braking) behavior in response to the FCW crash alert across a wide variety of initial vehicle-to-vehicle kinematic conditions, and the second parameter is the time it takes for the driver to respond to the crash alert and begin braking (which includes driver brake reaction time). These two parameters serve as input into straightforward vehicle kinematic equations which determine the alert range necessary to avoid a crash. These kinematic equations will be discussed following a discussion of the rationale for the values used for these two input parameters.

Rationale Underlying the Assumed Driver Deceleration Values

The first driver parameter which needs to be considered, driver deceleration (or braking) behavior in response to the onset of the FCW crash alert across a wide variety of initial vehicle-to-vehicle kinematic conditions, was addressed by the first CAMP human factors study (CAMP Study 1). In this closed-course, field study, a strategy was employed to initially develop a fundamental understanding of the timing and nature of drivers' "last-second" braking behavior without a FCW system, before conducting the subsequent FCW system driver interface studies. This strategy was taken so that drivers' perceptions of "normal" and "hard braking" kinematic situations could be properly identified and modeled for FCW system crash alert timing purposes. The underlying assumption is that properly characterizing (i.e., modeling) the kinematic conditions surrounding hard braking onsets without FCW system crash alert support will lead to a proper estimate for the assumed driver deceleration (or braking) behavior in response to a FCW system crash alert (across a wide variety of initial vehicle-to-vehicle kinematic conditions). This assumption was then evaluated and received strong validation in the subsequent three driver interface studies.

In this CAMP Study 1, drivers were asked to wait to brake until the last possible moment in order to avoid colliding with a "surrogate" (lead vehicle) target. Drivers performed these "last-second" braking judgments while approaching a parked surrogate target at speeds ranging between 30 and 60 MPH, and while "normally" following the lead vehicle (travelling at these same speeds) which eventually braked at a constant deceleration ranging between -0.15 and -0.39 g's. In performing these "last-second" braking judgments, subjects were instructed to use either "normal", "comfortable hard", or "hard braking" pressure. The use of these different braking instructions enabled properly identifying and modeling drivers' perceptions of "normal braking" (albeit "aggressive normal braking") and "hard braking" for crash alert timing purposes. Thirty-six younger (20-30 year old) drivers, 36 middle-aged (40-51 year old) drivers, and 36 older (60-71 year old) drivers were tested. Eighteen males and 18 females were tested in each age group. Overall, data from over 3,800 last-second braking trials were obtained. A key measure in interpreting these results was the "required deceleration" measure. This measure was defined as the constant deceleration level at braking onset required for the driver to avoid the crash. This measure was calculated by using the current speeds of the driver's vehicle and the lead vehicle, and assuming the lead vehicle continued to decelerate at the prevailing deceleration value (i.e., at the current "constant" rate of slowing).

Converging evidence suggested that the 50th percentile required deceleration value observed in CAMP Study 1 under "hard braking" driver instructions appeared very promising as an appropriate (not overly aggressive/not "underly" aggressive) estimate of the assumed driver braking onset range for crash alert timing purposes. Put in another way, the data suggested this required deceleration-based estimate would ensure that, for a high percentage of drivers, the onset of hard braking in response to a crash alert would occur at a closer range than their braking onset range during “aggressive” normal braking, and that this estimate would allow sufficient range for the driver to avoid the crash by hard braking. This required deceleration measure varied with driver speed and lead vehicle deceleration rates. It is also important to note that these required deceleration values were relatively uninfluenced by driver age or gender. Additional evidence suggested that drivers with a FCW-equipped vehicle would be capable of executing the observed hard braking levels without exceeding their “comfort zone” for hard braking.

The CAMP Study 1 data obtained from the “hard braking instruction” was then modeled. The primary goal of this modeling effort (which is described in detail in Appendix A20) was to predict “last-second”, “hard braking” onsets across the wide variety of initial vehicle-to-vehicle kinematic conditions examined in CAMP Study 1 by using the required deceleration value. Braking onset is defined here as the point in time in which the vehicle actually began to slow as a result of braking (rather than brake contact). The results of this modeling effort were used directly for crash alert timing purposes in the subsequent three FCW system driver interface studies. The raw data which were used for this modeling effort included:

R = Range between the driver’s vehicle and lead (surrogate target) vehicle

V_{SV} = Speed of the driver’s vehicle (or Subject Vehicle, referred to as the SV)

V_{POV} = Speed of the lead vehicle (or Principal Other Vehicle, referred to as the POV)

dec_{POV} = Deceleration level of the lead vehicle (or POV)

The resulting equation from this modeling effort, referred to as the CAMP Required Deceleration Parameter (RDP) equation, is shown below. In this equation, the following notation and measurement units are employed (negative deceleration values indicate braking or slowing):

dec_{REQ} = required deceleration of the SV, expressed in g’s

dec_{POV} = deceleration level of the POV, expressed in g’s

V_{SV} = velocity of the SV, expressed in meters/sec

V_{POV} = velocity of the POV, expressed in meters/sec

(the “if POV moving “ variable is explained below)

CAMP Required Deceleration Parameter (RDP) Equation

$$dec_{REQ} = -0.165 + 0.685(dec_{POV}) + 0.080(\text{if POV moving}) - 0.00877(V_{SV} - V_{POV})$$

In the above equation, the "$(V_{SV} – V_{POV})$" or *delta V* predictor variable represents the speed difference between the SV and POV *projected* at SV braking onset and "dec_{POV}" represents the current POV deceleration level. (The "projection" described here, as well as the projections described below, were performed to be consistent with the Study 1 modeling efforts which focused on predicting the moment of braking onset.) In addition, the "if POV moving" predictor variable is set to 0 if the POV is projected to be stopped at braking onset, and is set to 1 if the POV is projected to be moving at braking onset. These predicted required deceleration values (expressed in g's) serve as input into straightforward vehicle kinematic equations (described later) which determine the braking onset range necessary to avoid a crash.

The assumed driver deceleration (or braking) behavior in response to the FCW crash alert for the "too early" onset range cut-off is calculated using the RDP equation above. As should be clear, this "too early" onset range cut-off assumption is more focused on driver preference considerations for crash alert timing.

The assumed driver deceleration (or braking) behavior in response to the FCW crash alert for the "too late" onset range cut-off was based on examining driver's "actual" deceleration values under experimental conditions in which drivers were braking the hardest. The *actual deceleration* is defined as the constant deceleration level needed to yield the actual (observed) braking distance. For each speed condition examined in CAMP Study 1 (30, 45, and 60 MPH), the mean actual decelerations were highest (i.e., hardest, most intense) in the condition in which drivers were following the lead vehicle at their "normal" following distance, and the lead (surrogate) vehicle subsequently braked at -0.39 g's. The overall 85^{th} percentile (milder) actual deceleration values were then obtained at each speed condition examined when the lead vehicle braked at -0.39 g's. (The reader should note that the use of 85^{th} percentile actual deceleration values in this context corresponds to accommodating 85 percent of the observed driver braking capabilities, which corresponds to the 15^{th} percentile actual deceleration value shown earlier in Table 3-10.) The relationship between drivers' mean speed in these three speed conditions and these 85^{th} percentile actual deceleration values for this (hard) lead vehicle braking condition was linear, and resulted in the following equation derived from standard linear regression techniques. This equation will be referred to as the *CAMP actual deceleration parameter* equation, or *CAMP ADP* equation, which is shown below. In this equation, the following notation and measurement units are employed:

dec_{ACTUAL} = actual deceleration of the Subject Vehicle, expressed in g's (negative values indicate braking)

V_{SV} = velocity of the Subject Vehicle (or SV), expressed in meters/sec

CAMP actual deceleration parameter (ADP) equation

$$dec_{ACTUAL} = -0.260 - 0.00727(V_{SV})$$

At driver speeds of 30, 45, and 60 MPH, the above equation generates actual deceleration values of –0.36, -0.41, and –0.45 g's, respectively. As should be clear, this "too late" onset range cut-off is more focused on observed driver braking capability considerations, rather than driver preference or vehicle capability considerations.

Rationale Underlying the Assumed Driver Brake Reaction Time Values

The second fundamental driver behavior parameter which needs to be considered in developing a crash alert timing approach was addressed in three subsequent closed-course, field studies (CAMP Study 2, Study 3, and Study 4), where a wide range of naive and trained drivers of a FCW-equipped vehicle experienced various FCW system crash alert types under both *expected* and *unexpected (or surprise) braking event* conditions. Across these three driver interface studies during the surprise braking event conditions, several strategies were employed to ensure the driver experienced the crash alert and create a relatively “inattentive” driver (i.e., the criterion for triggering the crash alert was met). During the surprise braking event, the lead vehicle traveled at 30 MPH and braked at about -0.37 g’s without brakelights activated. Strategies employed to create a relatively “inattentive” driver included engaging the driver in natural conversation, asking the driver to respond to some background-type questions, and asking the driver to search the head-down, conventional instrument panel for a (non-existent) indicator light. In two of the three studies, drivers were completely unaware the vehicle was even equipped with FCW system crash alert prior to the unexpected, surprise braking event.

The assumed driver *brake reaction time* (or *brake RT*) values which were used in defining the acceptable crash alert timing zone below were derived from the last driver interface study (Study 4), but also accommodate findings from the two other driver interface studies (Study 2 and Study 3). This study asked 8 younger, 8 middle-aged, and 8 older drivers who were completely unaware the vehicle was equipped with a FCW system crash alert to search for a head-down, conventional instrument panel for a (non-existent) indicator light immediately prior to the introduction of the surprise braking event described above. The 85^{th} and 95^{th} percentile (i.e., longer) driver brake RTs to the crash alert from this study were 1.18 and 1.52 seconds, respectively. These RTs were used in calculating the “too late” and “too early” onset range cut-offs, respectively. It should be noted that the corresponding 85^{th} and 95^{th} percentile driver brake RTs in the two remaining driver interfaces studies (which together tested a total of 84 drivers) were very close, and slightly shorter, with respect to the relevant crash alert types.

Furthermore, these upper percentile values correspond well to the 85th-95th percentile driver perception-response time value of 1.5 seconds recommended by Olson (1996) for “reasonably” straightforward situations. (Olson (1996) provides a review of the driver-perception response time literature). More specifically, these values generally accommodate other relevant sources of previous “surprise” driver brake RT data (Johansson & Rumar, 1971; Olson & Sivak, 1986), as discussed in Chapter 3.

Kinematic Equations Employing These Assumed Driver Behavior Parameters

The assumed driver deceleration (or braking) behavior in response to the FCW crash alert (across a wide variety of initial vehicle-to-vehicle kinematic conditions) and the assumed driver brake reaction in response to the alert were input into straightforward kinematic equations. Given the two assumed driver behavior parameters described above, and assuming current speeds (for both the SV and POV) and the prevailing lead vehicle deceleration value, these kinematic equations produce a braking onset range such that the difference in speeds between the driver's vehicle and lead vehicle and the distance between the two vehicles reach zero values simultaneously (i.e., when the front bumper of the driver's vehicle barely contacts or touches the rear bumper of the lead vehicle).

The appropriate case equation used to calculate the braking onset range (Case 1, Case 2, or Case 3) is based on the projected movement state of the POV at braking onset (POV moving or POV stationary), and the projected movement state of the POV when the SV barely contacts the POV (contact when POV is moving or contact when POV is stationary) under the required deceleration prediction (or assumption). The speeds of the SV and POV are also projected at braking onset. The braking onset range is then calculated by inputting the predicted required deceleration value from the CAMP RDP equation into the appropriate case equation below. It should be noted that the variables need to be expressed in common measurement units (e.g., meters), which should be consistent with those used in calculating the predicted required deceleration values. Also, in these equations negative deceleration values indicate braking or slowing.

In the following case equations, the following notation is used:

BOR = Braking Onset Range in meters

V_{SVP} = SV velocity in meters/sec projected at SV braking onset

V_{POVP} = POV velocity in meters/sec projected at SV braking onset

dec_{SVR} = deceleration of the SV in meters/sec^2 in response to the alert

dec_{POV} = POV deceleration in meters/sec^2

Kinematic Case Equations Used to Calculate Braking Onset Range

Case 1: POV Stationary →

$$BOR = \frac{(V_{SVP})^2}{-2 \bullet (dec_{SVR})}$$

Case 2: POV Moving, contact when POV is moving →

$$BOR = \frac{(V_{SVP} - V_{POVP})^2}{-2 \bullet (dec_{SVR} - dec_{POV})}$$

Case 3: POV Moving, contact when POV is stationary →

$$BOR = \frac{(V_{SVP})^2}{-2 \bullet (dec_{SVR})} - \frac{(V_{POVP})^2}{-2 \bullet (dec_{POV})}$$

In calculating the braking onset range for the "too early" onset range cut-off, the dec_{SVR} is substituted by the calculated dec_{REQ} (or CAMP RDP equation) value described above. Similarly, in calculating the braking onset range for the "too late" onset range cut-off, the dec_{SVR} is substituted by the calculated dec_{ACTUAL} value described above.

This braking onset range, calculated as shown above, is added to a "*delay time range*" (described below), to calculate the warning range. The assumed "*delay time range*" between crash alert criterion violation and vehicle braking is then the expected decrease in range during a *delay time* (defined below), assuming current speeds (for both the SV and POV) and the prevailing lead vehicle deceleration value. The equation for this delay time range equation is shown below (where dec_{SVM} represents the current SV deceleration level), where negative deceleration values indicate slowing or braking.

Equation Used to Calculate Delay Time Range

$$\text{Delay Time Range}=((V_{SV} - V_{POV})(\text{Delay Time}))+(0.5\ (dec_{SV} - dec_{POV})((\text{Delay Time})^2))$$

The assumed *delay time* is the composite sum of two separate delay times, the driver brake RT delay and the brake system delay time. The *driver brake RT delay* is defined as the time between crash alert onset and when the brake switch is triggered by the driver. Based on discussions above, this delay was assumed to be 1.52 and 1.18 seconds for the "too early" and "too late" range cut-offs, respectively. The *brake system delay time* is defined as the time between braking onset and vehicle slowing, and is assumed to be 200 milliseconds. (The reader should note that the *interface delay time*, defined as the time between when the crash alert criterion was violated and when the crash alert was presented to the driver, is not directly relevant to meeting this requirement that the alert occur within the acceptable zone, but is obviously a factor which needs to be considered in the design of a FCW system.)

This delay time range is then added to the previously described braking onset range to calculate the warning range. That is,

WARNING RANGE = BRAKING ONSET RANGE +DELAY TIME RANGE

A FCW is likely to need the following information to meet these timing requirements: Range between the SV and the POV, SV speed, POV speed (or the time derivative of range), and approximate knowledge of POV (lead vehicle) deceleration. The level of knowledge needed to pass the tests of Chapter 5 is described in that chapter. Briefly, the ability to "bin" the level of lead vehicle deceleration to within approximately +/-0.05g with minimal time delay (about one second) should have enough information to meet the proposed minimum requirements. To compute approximate values for lead vehicle deceleration may require a FCW system to have better sensing or better processing capability than a system without such capability. This may mean the FCW system needs more complex technology to pass the requirements proposed here than if lead vehicle deceleration were not considered, which introduces the possibility of delayed time-to-deployment. This disadvantage, however, is outweighed by two arguments for the use of approximate knowledge of lead vehicle deceleration in the requirements. First, the human factors studies show that the timing model for driver's decisions to brake at the last second is strongly dependent on lead vehicle deceleration information. Second, the simulation and modeling work reported in Appendix C suggests that this knowledge allows FCW design to provide more potential reduction in harm for the same incidence of in-path nuisance alerts. That is, a system with the ability to consider lead vehicle deceleration is expected to give more satisfactory alert timing to drivers and therefore lead to more successful deployment.

Summary of Crash Alert Timing Requirement

In summary, this minimum requirement defines the acceptable crash Alert Zone for a FCW system without crash alert timing adjustability (which is allowed), and the latest, closest setting for a FCW system with crash alert timing adjustability. Hence, the driver is not allowed to adjust the crash alert timing below (or later than) the minimum level specified by this requirement.

Both the "too early" and "too late" onset range cut-offs, which define the boundaries of the acceptable crash-timing, are calculated based on inputting two fundamental driver behavior parameters into the straightforward kinematic "Case" equations described above. These two driver behavior parameters are the assumed driver deceleration (or braking) behavior in response to the FCW crash alert and the assumed time it takes for the driver to respond to the crash alert and begin braking (or driver brake RT). The reader should be reminded that this requirement does not specify that any particular crash alert timing approach be employed, but instead, simply requires that whatever crash alert timing approach is used yield performance consistent with the these minimum timing requirements.

For the “too early” onset range cut-off, the assumed driver deceleration in response to the crash alert is based on the CAMP RDP equation and an assumed driver brake RT to the crash alert of 1.52 seconds (a 95^{th} percentile driver brake RT). This is essentially identical to the crash alert timing approach which was employed during the surprise braking event trials in the three driver interface studies reported in Chapter 3 (the only negligible difference is that a 1.50 second brake RT was used in these studies). The reader should be reminded that these assumed brake RT values were based on surprise braking event data gathered with naive drivers who were completely unaware the vehicle was equipped with a FCW system, and who were distracted via a request to search the head-down, conventional instrument panel for a (non-existent) indicator light.

For the “too late” onset range cut-off, the assumed driver deceleration in response to the crash alert is based on the CAMP ADP equation (which generates a 85^{th} percentile “hard” actual deceleration as a function of driver speed) and an assumed driver brake RT to the crash alert of 1.18 seconds (an 85^{th} percentile driver brake RT). As mentioned above, at driver speeds of 30, 45, and 60 MPH, the CAMP ADP equation generates actual deceleration values of –0.36, -0.41, and –0.45 g’s, respectively.

The CAMP recommended crash alert approach is to design a FCW system with assumed driver behavior input parameters to the kinematic equations described above, as follows. First, the assumed deceleration in response to the crash alert should be predicted by the CAMP RDP equation (under the domain of validity for this equation, discussed further below). This braking onset assumption was employed throughout the three driver interface studies reported in Chapter 3. Second, the assumed driver brake RT in response to the crash alert should be 1.18 seconds, which corresponds to the 85^{th} percentile driver brake RT described above.

It should be noted that combining an X^{th} (e.g., 85^{th}) percentile driver deceleration in response to the crash alert (either required or actual deceleration) and an X^{th} (e.g., 85^{th}) percentile brake RT does not necessarily imply an assumed “overall” X^{th} (e.g., 85^{th}) percentile driver. Indeed, under surprise braking event conditions, the Pearson correlation coefficients between required deceleration values and brake RTs across all three driver interface studies ranged between -0.13 and +0.64, and the corresponding correlation coefficients between actual deceleration values and brake RTs ranged between +0.48 and +0.62. A positive correlation here indicates longer brake RTs were associated with harder (required or actual) decelerations. Together, these data suggest that the current CAMP assumptions for both the “too early” and “too late” onset range cut-offs may account for higher than an 85^{th} percentile “overall” driver from both a driver preference perspective and a driver capability (rather than vehicle capability) perspective, respectively.

On a final note, for readers concerned with the details of implementing crash alert timing equations, it should be noted that the kinematic equations shown above are focused on closing scenarios. In a production implementation, a crash alert algorithm will be exposed to a wide variety of driving situations, which will include the key closing scenario elements shown above, as well as the additional logic and equations required so that inappropriate alerts do not occur in normal, non-braking situations (e.g., when the range between the vehicles is increasing), and so that alerts are presented in more unusual circumstances with crash alert timing that is equivalent to that described here. The interested reader is referred to Appendix B for a more detailed discussion of computing alert timing values and the domain of validity for these equations. This appendix presents the explicit instructions for computing timing requirements, and also includes a few subtleties that are not presented here in the interest of brevity, but that prove significant in some situations.

The driver should not have the ability to turn off the FCW system and associated FCW crash alerts inadvertently or otherwise (It should be stressed that subsequent technology experience with FCW systems might suggest allowing the driver the capability of turning the system off to reduce nuisance alerts, in which case the system should default to an "ON" state with each ignition cycle.)

The FCW system may have a feature which allows the crash alert timing to be adjustable by the driver.

For a FCW system without crash alert timing adjustability, the crash alert timing shall fall within the "too early" and "too late" onset range cut-offs as defined above. (The "too late" cut-off does not need to be more than 100 meters range, for reasons described later, in Section 4.3.2.1.)

For a FCW system with crash alert timing adjustability, the minimum (latest, closest) crash alert timing setting shall fall within the "too early" and "too late" onset range cut-offs as defined above.

Note: These cut-offs were based on inputting the following driver behavior parameters into the straightforward kinematic equations described above. (The reader is referred to Chapter 6, Appendix B for a discussion of the domain of validity of these equations.) For the "too early" onset range cut-off, the assumed driver deceleration in response to the crash alert is based on the CAMP RDP equation and an assumed driver brake RT of 1.52 seconds (a 95th percentile driver brake RT). For the "too late" onset range cut-off, the assumed driver deceleration in response to the crash alert was based on the CAMP ADP equation and an assumed driver brake RT of 1.18 seconds (an 85th percentile driver brake RT).

Recommended Approach*: *The FCW system should be designed with assumed driver behavior input parameters to the kinematic equations described above, as follows. The assumed driver deceleration in response to the crash alert should be predicted by the CAMP RDP equation, and the assumed driver brake reaction time should be 1.18 seconds (corresponding to an 85th percentile driver brake RT). The domain of validity of this equation is discussed in the text.

(2)

4.2.3.2 Control for Adjusting Crash Alert Timing

For a FCW system with crash alert timing adjustability, the corresponding control and crash alert timing setting should be clearly and easily comprehended by the driver. The adjustment of the control could allow the driver to have continuous control, or the control could be limited to a fixed number of settings (e.g., 2 or 3). A rotary control, slide, or a thumbwheel control should be the type of control used (MIL-STD-1472D, 1987; Sanders and McCormick, 1987). In order to be consistent with strong population stereotypes for these controls reported by Wierwille and McFarlane (1991), the following recommendations are offered, although further research is suggested in this area. Dependent on the orientation, operation, and type of control, either an "up", "right", or "forward" movement should result in an earlier (farther) crash alert criterion, with the opposite analogous movements corresponding to a later (closer) crash alert criterion.

Nomenclature used to indicate minimum (latest, closest) and maximum (earliest, farthest) settings of the crash alert criterion on the associated control might include "CLOSER" and "FARTHER", or "NEAR" and "FAR". The former nomenclature was used for an adaptive cruise control system in the University of Michigan Transportation Research Institute (UMTRI) field trials (J.R. Sayer, personal communication, February 18, 1996), and the latter nomenclature received some support in a driver preference study examining labels of adjustable distance controls for an adaptive cruise control system (Serafin, 1997). Interestingly, this latter study was not able to find a symbolic manner of labeling the controls (i.e., using arrows or chevrons) which outperformed the "NEAR" and "FAR" word labeling. However, one strong advantage of symbology relative to word labeling is their relatively universal applicability across international driving populations. Expert judgment suggests that, providing they are legible, words should be spelled out, in order to increase the driver's comprehension of the control setting. At this point, no firm recommendations are made with respect to control labeling nomenclature.

If the FCW system allows the driver the ability to adjust the crash alert criterion, the associated control and the crash alert criterion shall be clearly labeled and easily comprehended by the driver.

A rotary control, slide, or thumbwheel control should be the type of control provided for this crash alert timing adjustment.

This crash alert timing control and the associated control labeling should be consistent with population stereotypes for control/display relationships. (3)

4.2.4 How Should Crash Alert Information be Presented to the Driver?

Visual, audio, and/or haptic alerts have all been suggested as potential means of providing the driver with crash alert information. *Haptic* alerts refer to any warning that is presented through the proprioceptive (or kinesthetic) senses, such as a brake pulse deceleration (vehicle jerk), accelerator pushback or vibration, steering wheel vibration, or seat vibration.

The CAMP driver interface studies focused exclusively on examining multi-modality (primarily dual-modality) crash alerts. The rationale for evaluating dual-modality warnings in these studies was based on the notion that an omnidirectional component of the crash alert (i.e., an auditory or haptic component) was required which was independent of where the driver was directing visual attention. Inattentive or distracted drivers (who play large roles in rear-end crashes) may not detect a visual crash alert display, since their visual attention may be directed elsewhere (e.g., at an instrument panel display) at the same time the alert is initially presented. In addition, it was felt that including a (non-omnidirectional) visual crash alert component was a prudent strategy for a crash alert modality approach. A visual crash alert is recommended in order to accommodate drivers who may not hear the alert sound either due to hearing impairments (e.g., older, hearing-impaired drivers or deaf drivers) and/or competing noises coming from either inside or outside the vehicle. One advantage of visual over auditory displays is that whereas driver licensing requirements in most states in the United States generally do require a minimum level of visual performance (e.g., 20/40 far acuity, adequate peripheral vision), they generally do not require any minimum level of auditory performance. Additional important reasons for including a visual alert modality component are to potentially facilitate the driver to look ahead in response to the crash alert if they are not currently looking ahead at the forward scene, and to help explain the omnidirectional component of the alert to the driver. With respect to this latter point, it is currently common industry practice to provide a visual indicator for most telltale-related sounds.

Across the three CAMP driver interface studies, six separate crash alert types were evaluated in which the driver was simultaneously presented crash alerts from two sensory modalities (with one exception involving three modalities), sometimes referred to as a *1-stage, dual-modality crash alert*. The crash alert type conditions which were tested are indicated below:

- Head-Up Display + Non-Speech Tone
- High Head-Down Display + Non-Speech Tone
- High Head-Down Display + Speech message
- High Head-Down Display + Brake Pulse
- High Head-Down Display + Non-Speech Tone + Brake Pulse
- Flashing High Head-Down Display + Non-Speech Tone (for the other crash alert types, the HHDD was not flashed and remained steady)

The visual alert components evaluated included a "high" head-down display (or HHDD) and a head-up display (or HUD). The visual format of these displays (discussed in Section 2.4.3) was selected from a set of alternatives by using an established ANSI procedure for evaluating candidate symbols (see Chapter 3, Appendix A18). The auditory alert components evaluated included a non-speech sound and a speech sound (the word "warning" repeated), which were played through the front car speakers. These two sounds were selected based on a laboratory study involving drivers rating various alternative sounds on crash alert properties (see Chapter 3, Appendix A19). The haptic alert evaluated was a brief brake pulse, or "vehicle jerk" alert (see Chapter 3). This alert was examined with more of an intent to explore its potential, since unlike the visual and auditory alerts examined here, there are important unresolved implementation and driver behavior issues surrounding this alert. These issues include alert activation on slippery surfaces, onset delays, consequences of moving the driver (and their foot) from their "normal" position in the car, inhibiting more appropriate steering responses, and driver annoyance (associated with nuisance alerts) surrounding the brake pulse alert. It should be noted that these concerns are equally true for other, relatively immature, haptic alerts which have been suggested (e.g., accelerator pedal pushback, steering wheel vibration, seat vibration).

To summarize the interface studies discussed in detail in Chapter 3, of the 1-stage, FCW crash alert types examined, the "Flashing HHDD + Non-Speech Tone" is recommended as a near-term approach (Replacing the flashing HHDD with a "steady" HUD" is also supported by these findings.). The "Steady HHDD + Non-Speech Tone" crash alert type provided good all-around performance in terms of both objective data (e.g., fast driver brake RTs) and subjective data (e.g., low driver annoyance). The recommendation to flash the HHDD is primarily based on improving the noticeability of the HHDD for drivers who may not hear the non-speech tone either due to hearing impairments and/or noises coming from either inside or outside the vehicle. Other considerations include potentially facilitating the driver to look ahead in response to the visual crash alert, and using this visual alert to help explain the non-speech tone to the driver. The recommended visual display format (a "car-star-car" crash icon with the word "WARNING" printed below) and non-speech tone correspond to those tested in these three interface studies.

Although a multiple-stage alert is allowed under the proposed requirement, a 1-Stage alert is recommended based on the current discovery of a proper "single-point" crash alert timing approach, compatibility with 1-stage ACC system driver alerts being considered, simplicity/elegance from a customer education (mental model) and production implementation perspective, minimizing nuisance alerts (which can reduce system effectiveness), and the rapid (potentially confusing) sequencing of multi-stage alerts in many closing scenarios likely to trigger crash alerts. Indeed, one could argue that multiple-stage (e.g., 2-stage) alerts should be avoided unless the advantages of using such alerts outweigh the disadvantages of such alerts.

A critical consideration in recommending the "Flashing HHDD + Non-Speech Tone" alert as a near-term FCW crash alert approach is that this alert type has favorable qualities from an industry-wide, international implementation perspective relative to the HUD, brake pulse, and speech crash alert components examined. (In any case, the speech alert component performed poorly in terms of both objective and subjective data.) In the near-term, HUDs will not be implemented industry-wide. Furthermore, as discussed above, there are important unresolved implementation and driver behavior issues surrounding the brake pulse alert (and haptic alerts in general).

For these reasons, the dual-modality (1-stage) Flashing HHDD + Non-Speech crash alert (where a HUD can be substituted for the HHDD) is recommended. However, a single-modality alert including the CAMP non-speech tone is not prevented by the following minimum requirement, in part because such an approach was not evaluated in the CAMP human factors studies. The details surrounding the implementation of the CAMP non-speech tone crash alert and the CAMP visual crash alert are discussed in greater in Section 4.2.4.1 and Section 4.2.4.2, respectively.

As was mentioned at the end of Section 4.2.2 the FCW system is allowed (although not recommended) to have multiple-stage (e.g., 2-Stage) FCW crash alerts, provided additional stages shall not reduce the effectiveness of the most imminent (latest, closest) alert and all CAMP minimum requirements are met for both a fixed FCW system and for the minimum (latest, closest) setting for a FCW system which provides crash alert timing adjustability. The overall intent is to have any earlier stage alert be clearly distinguishable from subsequent (later, closer) alert stages, yet still clearly integrated with this later alert from a simple "mental model", driver comprehension perspective. For example, the driver might observe the light (visual crash alert) is first steady and then it flashes as the driver gets closer to the car ahead, or that the non-speech tone speeds up as the driver gets closer to the car ahead.

Some potential multiple-stage approaches which have a better chance of meeting the CAMP minimum requirements are to precede the proposed CAMP “flashing” visual crash alert display with the corresponding “steady” (or continuous) version of this display, and/or precede the proposed CAMP Non-Speech Tone with a less “imminent” version of this sound. Some possible approaches to creating a less imminent version of this sound are decreasing the speed or rate of the sound, increasing the dead time between sound bursts (see Appendix A18), using lower frequencies within the same general sound pattern, and/or increasing the loudness of the tone. (It should be noted that if this latter loudness approach is employed, it should be combined with one or more of the other approaches suggested above.)

Finally, unlike the visual and auditory alerts examined here, there are important unresolved implementation and driver behavior issues surrounding the brake pulse alert. It should be noted that these concerns are equally true for other, relatively immature, haptic alerts which have been suggested and were mentioned earlier. If these major issues surrounding the brake pulse alert could be satisfactorily resolved, these exploratory results suggest that the “vehicle slowing” afforded by the brake pulse during the interval immediately prior to the driver taking evasive control action (in response to the crash alert) might be advantageous, and that the brake pulse should be “explained” by coupling it with an auditory and visual alert component. Consequently, although a haptic alert is allowed under the current minimum requirement (however, only as a supplement to the dual-modality approach), it is not currently advised due to the numerous unresolved implementation and driver behavior issues surrounding these haptic alerts.

If a single-modality crash alert is implemented, the CAMP non-speech tone shall be used for the alert.

If a dual-modality crash alert is implemented, the CAMP non-speech tone and the CAMP visual crash icon (which can be shown on either a HHDD or HUD) shall be used for these auditory and visual, respectively. An additional haptic alert may be added to this dual-modality crash alert, however, due to the unresolved implementation and driver behavior issues surrounding this type of an alert, such an approach is not currently advised.

Recommended Approach:* *The system should have a dual-modality crash alert as specified above, with the exception that the capitalized word “WARNING” should be positioned centered and below the crash alert icon. **(4)**

4.2.4.1 The CAMP Non-Speech Tone Crash Alert

Non-speech auditory alerts refer to tones, chimes, beeps, buzzers, and “earcons” (e.g., the sound of screeching tires or a horn). That is, any sound that is not a word. Two strong advantages of non-speech relative to speech crash alerts are that they do not require familiarity with any particular spoken language, and that they provide the advantage of using the same design for vehicles sold in international markets.

The recommendation for the CAMP non-speech tone is based on three lines of reasoning. First, this particular non-speech tone was down-sized from a large number of alternatives, which had been examined in previous work by Tan and Lerner (1995), and in additional human factors work completed by CAMP (see Chapter 3, Appendix A19 for a detailed description of this study). The CAMP sound study built directly upon previous work conducted by Tan and Lerner. The CAMP sound study asked subjects to rate sounds on the extent to which each sound was associated with various crash alert related attributes. These sound attributes included overall effectiveness, noticeability, confusability, attention-getting qualities, startle, interference with driver decisions, interference with performing driving actions, annoyance assuming alert occurred once a day where no driving action was required, annoyance assuming alert occurred once a day where no driving action was required, appropriateness of the alert in a car or truck, and alert association with an emergency situation. (The reader should note that the annoyance assumptions stated above are consistent with the in-path and out-of-path assumptions stated later in this Chapter.) The interior sound of a 1997 Ford Taurus SHO traveling on dry, smooth pavement at 70 MPH was used as background noise during these sound ratings.

In their previous work, Tan and Lerner (1995) examined 26 sounds, including various non-speech, earcon (car horn and tire skid), and speech sounds. The CAMP sound study, employing nearly the identical methodology employed by Tan and Lerner, examined 15 non-speech and 3 speech sounds, including the 5 top-rated sounds from the previous Tan and Lerner study (which were all non-speech sounds). Hence, in some sense, together, these two studies have examined 39 distinct sounds, including 22 distinct non-speech sounds, 15 distinct speech sounds (all using either the word “warning”, “danger”, “look out” , or “hazard”), and 2 distinct earcon-type sounds (car horn, tire skid). Hence, the top-rated non-speech and speech sounds observed in this CAMP sound rating study provided a sound empirical justification for the selection of the non-speech sound used in the follow-up, closed-course, driver-interface studies.

Based on these CAMP findings, the CAMP non-speech tone (Sound #8; which corresponds to Stimuli 10 in the earlier Tan and Lerner study) was used for all three driver interface studies (i.e., Study 2, Study 3, and Study 4) as the non-speech alert sound, which was played through the front speakers. A 1/3 octave band and time series analysis of this non-speech sound can be found in the Tan and Lerner paper (see Appendex B, page B-10 in this paper). This 2.1 second long non-speech sound involved repeating the exact same macro “sound pattern” (or macro sound burst) four times. Each repetition of the macro sound pattern was followed by 110 milliseconds of silence. Each macro sound pattern in turn involved repeating the exact same micro sound pattern (or micro sound burst) four times. These micro sound bursts, which are the building blocks for a macro sound burst, consisted of narrow 2500 Hz and 2650 Hz peaks.

The second basis for the recommendation of the CAMP non-speech tone is that this sound was used for all three CAMP driver interfaces studies described in Chapter 3. These studies gathered data under highly valid, controlled, realistic conditions involving a wide range of drivers braking to a realistic crash threat while experiencing production-oriented crash alert types. Hence, the CAMP non-speech tone is well understood in terms of the expected distribution of driver brake RTs to a crash alert type including this component under both unexpected (surprise) and expected braking event conditions with both trained and naive drivers. (It is assumed that the visual alert in these studies played a very minor role, if any, in effecting driver brake RTs, particularly under expected braking event conditions.) The brake RT findings obtained with this sound included as part of the crash alert type are the underlying basis for the driver brake RTs in response to a crash alert assumed previously in Section 4.2.3. These driver brake reaction assumptions cannot be automatically assumed to generalize to other sounds. Most importantly, these driver interface studies demonstrated this alert sound was successful in terms of allowing both trained and naive FCW system users to avoid impact with the lead (surrogate) vehicle under surprise braking event conditions.

The third basis for the recommendation for the CAMP non-speech tone is that since it is far more difficult to commonize the visual alert location across vehicles, and a visual alert is not currently required to comply with these minimum requirements, it becomes increasingly important that a common sound be used across vehicles to convey FCW system crash alert information.

As was mentioned above, the CAMP non-speech tone was played through the front speakers during the three driver-interface studies. This tone should emanate from the front of the vehicle (the direction of the hazard) and not in the *median plane*, that is perpendicular to the horizontal plane that passes through the driver's ears. A recent laboratory study by Tan and Lerner (1996) suggests that both the precise nature of the auditory crash alert (i.e., the warning sound) and the acoustic source of this alert (i.e., the speaker location) are important considerations in determining whether an auditory crash alert will allow the driver to effectively localize a crash threat. Finally, the ISO draft (1996b) suggested that an auditory crash alert should not have the ability to be disabled, as it conveys safety-critical information.

The CAMP non-speech tone shall be used as the auditory crash alert.

The CAMP non-speech tone shall be presented so that this sound is perceived to emanate from the forward direction of travel of the vehicle (i.e., the location of the potential crash threat).

The CAMP non-speech tone shall not have the ability to be turned off inadvertently or otherwise. (5)

Sound Intensity

Sound intensity, or the sensation of loudness, is measured as a sound pressure level and reported in decibels (dB). There are four different decibel scales; A, B, C and D. The A (dBA) scale is most commonly used to measure environmental noise, since it comes closest to approximating the response of the human ear. The CAMP non-speech tone was played at approximately 75 dbA in 2 of the 3 CAMP driver interface studies, including the study from which the underlying basis for the driver brake RTs assumed in Section 4.2.3 for crash alert timing purposes are derived. Delco also used a 75 dBA sound level in their proposed Forward Collision Warning system (Landau, 1995).

In these CAMP driver interface studies, drivers' rated the loudness of the sound, overall, as "just right" loudness, based on hearing the crash alert while driving at speeds ranging from approximately 30 to 60 MPH. However, it should be noted that competing noises from both inside and outside the vehicle were primarily limited to road noise (e.g., music was not playing, and there was no nearby traffic). Overall, about 3 of 4 subjects felt that the radio should be muted during the crash alert. However, it should be noted that these drivers had no direct experience with various types of in-path ("too early") and out-of-path nuisance alerts, which could change this preference for radio muting. In a description of a Delco Forward Collision

Warning system, Landau (1995) suggests that "other audio systems in the vehicle must be muted whenever generating audible warnings."

One problem with stating a minimum requirement for sound intensity is that such a requirement is dependent on the ambient noise levels, which are dependent on both interior and exterior noise levels, which vary from car to car. Antin, Lauretta, and Wolf (1991) reported interior sound levels ranging from 42 - 57 dBA while the vehicle was idling and up to 64 - 72 dBA at 60 mph. To add to the sound levels, some car stereos have the ability to reach levels over 100 dBA. Hence, short of constantly monitoring the noise level and adjusting the output of the alert sound accordingly (ISO, 1996b), muting systems which generate significant noise (e.g., car stereos) appears the best reasonable near-term solution. However, this recommendation could prove problematic if a FCW system produces an excessive amount of in-path ("too early") and/or out-of-path nuisance alerts.

The intensity of the CAMP non-speech tone should be 75 dBA.

Any vehicle systems which generate significant interior noise and competing auditory information to the driver (e.g., stereo system, fan, cellular phone) should be muted during the presentation of the CAMP non-speech tone. (6)

4.2.4.2 The CAMP Visual Crash Alert

This visual crash alert information could potentially be presented either at conventional head-down display locations or on *a head-up display* (or *HUD*). The potential head-down locations to consider include primarily instrument panel, center-mounted console, or top-of-dashboard locations.

Location

The location refers to the position of the display in the driver's forward view, with respect to a seated driver who is looking straight ahead at the roadway in front of a vehicle. This location may be referred to in either qualitative terms (e.g., centered or centerline to the driver, to the left of the driver), or in more quantitative terms (e.g., 5° to the left of the driver).

The visual crash alert component evaluated in the CAMP driver interface studies included a "high" head-down display and a HUD, which are discussed in detail in Chapter 3. These displays were chosen as representative of current production displays. The visual format of these displays were nearly identical, and are discussed in the following section, *Display Format.*

Although a display at the conventional, head-down instrument panel was implemented in the CAMP test vehicle employed in the three interface studies, it was not subject to testing because of "noticeability" concerns, and because it ran directly counter to facilitating the driver to look ahead in response to the crash alert if they are not currently looking ahead at the forward scene. The "noticeability" concerns are supported by results from the Grant, Kiefer, and Wierwille et al. (1995) road study. In this study (which employed the GM HUD design), during a short familiarization drive, an unexpected red brake telltale was presented up to four times during either a HUD or a conventional, head-down, dashboard location condition. During the first 1-second presentation of the telltale, 7 of the 8 drivers fixated the activated telltale in the head- up condition, whereas only 2 of the 8 drivers fixated the activated telltale in the head- down condition. These results suggested that driver's ability to detect FCW system crash alert information may be improved by employing a HUD location relative to a conventional, head-down, dashboard location for this information.

The high head-down display evaluated in the CAMP driver interface studies was placed on top of the instrument panel, close to the cowl of the windshield, and centerline to the driver. With respect to the eyellipse centroid, the center of the icon was positioned at a 7.7^0 look-down angle below the driver's visual horizon, and at a 0.947 meter distance. For a reference point, the look-down angle to the front hood of the test vehicle (i.e., where the hood visually occludes the roadway) was also 7.7^0, and the center of the conventional, head-down, instrument panel display was at a 19.3^0 look-down angle. This implies that for a 5^{th} percentile female driver, the HHDD as implemented would occlude a small portion of the visual field directly in front of the driver, and potentially be visually occluded by the steering wheel. This indicates the difficult challenge of implementing a HHDD which can be viewed by shorter drivers such that it is not obscured by the top of the steering wheel, and it does not interfere with their normal view of the road ahead.

The head-up display (or HUD) image evaluated in the CAMP driver interface studies was projected off a combiner and appeared below the driver's line of sight and centerline to the driver. With respect to the eyellipse centroid, the HUD image appeared at approximately a 1.214 meter image distance. The HUD look-down angle (relative to the driver's visual horizon) was adjustable by the driver, and was not measured individually for each subject (which is a time-consuming procedure). Since the aftermarket HUD used was not designed for the test vehicle, there is no straightforward way to characterize the HUD look-down angle. However, given that subjects were instructed to, and were able to, adjust the HUD to be positioned above the front hood, a lower bound for the bottom of HUD crash alert display is the look-down angle to the front hood, which was 7.7^0 relative to the eyellipse centroid. Based on previous HUD experience, the "nominal" look-down angle to this HUD crash alert was likely to be about 4^0 to 5^0.

It should also be noted that, although there are technical challenges associated with HUD visibility (ensuring visibility under a wider range of driving conditions), the HUD has the advantage (relative to a head-down display) of not being obscured by the steering wheel or the driver's hands provided the HUD eye box size is adequate. (See Beyerlein (1995) for a discussion of HUD luminance limitations/technological challenges).

Although there were no significant driver performance advantages found between the HUD relative to the HHDD visual alert across the CAMP driver interface studies, the HUD consistently outperformed the steady HHDD and flashing HHDD visual crash alerts on driver preference-related measures.

Finally, given the challenges of implementing either a HHDD or HUD in some vehicles, some discussion is merited regarding how a "low" head-down display (or LHDD) might also be used to augment the CAMP non-speech tone. A LHDD refers primarily to displays located at the conventional, instrument panel, dashboard location, or at center-mounted console areas in the vehicle. If the LHDD is the only viable option for a visual display associated with the activation of the FCW crash alert, it should not be presented simultaneously with the tone since it may direct the driver's eyes away from the forward scene precisely at a time when they should be attending to the forward scene. Instead, the LHDD presentation period shall begin immediately after the crash alert criterion is no longer violated following a crash alert activation. The purpose of this "post-alert confirmation display" is to help explain to the driver the association between the tone and the FCW system (the CAMP visual alert icon should be used), which is consistent with current common industry practice to provide a visual indicator for most telltale-related sounds. The implementation details surrounding the presentation duration and the underlying criterion for triggering the onset of this LHDD needs further development, and no recommendations along those lines are provided here.

If a visual crash alert is used as part of a dual-modality approach (which is not required, but recommended), the CAMP visual crash alert icon shall be presented at either a HUD or HHDD location. A LHDD shall not be used for visual crash alert purposes, but may be used for a "post-alert" confirmation display (explained in text above). This LHDD shall also use the CAMP visual crash alert icon.

If the visual crash alert is presented at the HHDD location, the alert should be located as follows. To the extent possible, for a 5th percentile (shorter) female driver, the top of the HHDD should be located centerline to the driver such that it is not obscured by the steering wheel (or other vehicle structures), and such that it is below the look-down angle to the front hood (i.e., where the hood visually occludes the roadway for this shorter driver). This recommendation generally implies a top-of-dashboard location for the HHDD. Qualitatively, the intent of this objective is to allow shorter drivers the capability of viewing the entire HHDD slightly below the front hood while minimizing any potential obscuration to the forward scene associated with the HHDD for these shorter drivers.

If the visual crash alert is presented at a HUD location, the alert should be located as follows. To the extent possible, the alert should be located centerline to the driver, and at front bumper distance (or about 2.4 m). Furthermore, the top of the HUD image should be 4.5° or more below the drivers' line-of-sight, and the bottom of the HUD image should be above the hoodline. Qualitatively, the intent of this latter vertical image location objective is to allow drivers the capability of viewing the HUD image slightly above the front hood. (7)

Display Format

Display format refers to the words and/or icons used as the symbology for the visual crash alert. Icons refer to picture symbols commonly used as substitutes for words for identifying controls and displays (e.g., telltales). Three strong advantages of using icons over words is that they do not require familiarity with any particular written language, icons generally require less display space than words, and icons provide the advantage of using the same design for vehicles sold in international markets. In general, crash alert icons should be intuitive, meaningful, and visually simple (space constraints in today's vehicles argues against any complex symbology), and quickly and accurately recognized under relatively brief viewing conditions.

If a visual crash alert is presented (which is recommended), the requirement for the CAMP visual crash alert icon is based on human factors work completed by CAMP. This icon, Symbol 1 below, was downsized from the set of 10 alert candidates shown below. (See Appendix A19 for a detailed description of this visual display format selection process.)

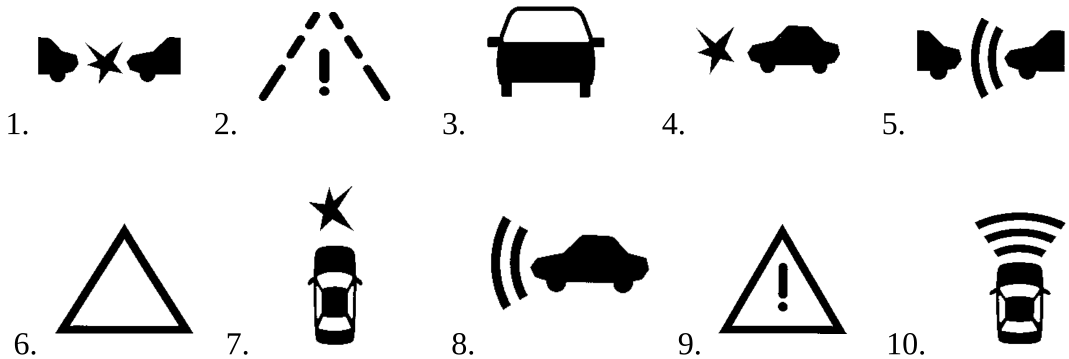


Figure 4-3 Candidate FCW Alert Icons

The design of the 10 candidate icons initiated with a review of the visual crash alerts tested in a previous study (Jovanis, Campbell, Klaver, & Chen, 1997), production symbols contained in ISO 2575/1 (1996), and symbols proposed for adaptive and conventional cruise control systems. "Crude" candidate icon drawings were then forwarded to designers from the Controls and Displays Center at the General Motors Design Center, who assisted with the symbol review and design process. These designers were familiar with ISO graphics constraints and ISO vehicle orientation stereotypes.

These icons were then evaluated in accordance with the American National Standards Institute (ANSI) Z535.3 (1997) procedure for evaluating candidate symbols. The first stage in this process is a comprehension estimation procedure used for the purpose of identifying poor symbols prior to open-ended comprehension testing. The procedure involves informing participants of the intended message of a symbol and then asking them to estimate the percentage of the population they believe would understand the message of the symbol. According to the standard, only symbols with mean comprehension estimations of 65% or greater merit further testing in the second stage of this ANSI Z535.3 process, which involved an open-ended comprehension procedure. In this latter procedure, participant are provided a symbol with the appropriate context, and asked to provide written open-ended interpretations of the symbol. The ANSI Z535.3 recommended criterion for acceptance of a symbol is that 85% of participants provide correct interpretations of the symbol, and that a maximum of 5% of participants provide interpretations considered critical confusions for the symbol.

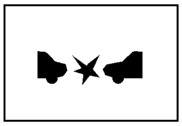
As a result of both the comprehension estimation and open-ended comprehension test procedures administered in accordance with ANSI Z535.3 process, the CAMP visual crash alert icon mentioned above was selected as the top choice of the 10 icons evaluated. It was also found that adding the capitalized word WARNING to this icon increased comprehension estimates by about 20%. Hence, the CAMP visual crash alert icon with the capitalized word "WARNING" (positioned directly below the icon, centered relative to the icon) was used for all three driver interface studies as the visual crash alert display format. These CAMP results provided a sound empirical justification for the selection of the visual display format used in the follow-up, closed-course, driver-interface studies, and provided a sound empirical justification for the minimum requirement stated below.

Crash alert icons should also be large enough so that under rapid viewing conditions drivers can quickly and accurately recognize the icon. General recommendations for icon size are difficult to specify since it will depend upon many factors, including the icon familiarity, importance, criticality, time-course of presentation, level of detail/complexity, and color.

International Standards Organization (ISO) standards are sometimes incorporated into International Regulations, which are requirements for selling cars in many countries. ISO standards suggest an illuminated area for a variety of displays of at least 18 mm^2 (inside which the display can be identified), with the amount of driver head movement permitted (to overcome any obscurations) dependent on telltale criticality. These displays include the automatic gear position, choke, high beam indicator, turn signals, and a variety of telltales (brake, parking brake, hazard warning, seat belt, passive restraint readiness, engine coolant temperature, oil pressure, and electrical or battery charge). (It should be noted that these requirements for the illuminated telltale area sometimes conflict with minimum size requirements for identifying words or symbols contained within these areas.) This minimum size guideline (18 mm^2) subtends an area of 0.34° by 0.34°area. In the three CAMP driver interface studies, the area encompassed by the HHDD visual icon subtended a 0.3° high by 0.9° wide visual angle area, whereas the area encompassed by the HUD visual icon subtended a 0.7° high by 2.5° wide visual angle area.

In addition to these requirements, for cars sold in the United States, there are FMVSS size requirements for various instrument panel displays, including the high beam indicator, turn signals, and brake telltale. These head-down display requirements are stated in terms of minimum absolute size, and assume a 28-inch (or 711 mm) viewing distance. For example, the letters used in brake telltales must be 1/8 inch in height. The letter height corresponding to this 28-inch distance is a 0.26° visual angle. In the three CAMP driver interface studies, the area encompassed by the word “WARNING” on the HHDD subtended a 0.2° high by 1.2° wide visual angle area. The corresponding area subtended by the HUD was a 0.5° high by 3.4° wide visual angle area.

If a visual crash alert is used, the CAMP visual alert icon shall be used, which is shown to the right:



The CAMP visual alert icon shall be filled (as opposed to outlined).

The size of the CAMP visual alert icon should correspond to the total area subtended by a minimun of a 0.34° high by 0.90° wide area.

If words are used to supplement the CAMP visual alert icon, the capitalized word "WARNING" is suggested, which should be positioned directly below the icon, and centered relative to the icon. In addition, the height of these letters shall subtend a minimum of 0.26°.

***Recommended Approach*: *If provided, the visual crash alert should include both the visual CAMP crash alert icon and the word "WARNING" as specified above.* (8)**

Flash Rate

Flash rate is defined as the number of times per second a visual crash alert reaches an on and off state. Based on pilot work done in preparation for the last two CAMP driver interface studies, which examined the "Flashing HHDD + Non-Speech Tone" crash alert type, a flash rate of 4 times per second was employed in these studies. Sanders and McCormick (1987) recommends a flash rate of 3 to 10 flashes per second, with 4 per second optimal. In human factors experimentation, both McGehee et al. (1993) and Frontier (1995) have previously employed a flash rate of 4 times per second.

The flash rate for the CAMP visual alert display should be 4 times per second. (9)

Color

Our sensation or perception of *color* is derived from variations in the wavelength or spectral composition of light. Color perception can be described in terms of three psychological dimensions: *hue*, *saturation*, and *brightness*. *Hue* is related to the dominant wavelength of the stimulus and is typically equated with the word "color". *Saturation* is related to the degree of color purity (i.e., the extent to which multiple wavelengths contribute to a color sensation), such that desaturated colors are perceived as closer to white (i.e., more pale) while saturated colors are perceived as more vivid. *Brightness* is related to the amount of light emitted from a stimulus.

North American population stereotypes (or meaning associations) for the color green include go/power on/proceed/normal safe conditions/fully operational system; for the color yellow include proceed with caution/slow down/prepare to stop/potential hazard exists or developing; for the color blue include cold/information only; and for the color red include warning/stop/hazard, danger, or failure exists/malfunction or error/urgent, immediate action required/vehicle parameter outside of recommended range.

This use of color convention is commonly applied to various types of driver displays, including telltale indicators, gages (i.e., out-of-range markings), and interior temperature controls. In addition, there are FMVVS color requirements for certain displays which conform to these color stereotypes, including turn signals (green), seat belt and brake telltales (red or red-orange), anti-lock brake telltale (yellow), and high beam indicator (blue, green, or blue-green).

Color coding can also potentially be an effective and quick means to direct an operator's attention to important information, but this advantage is highly situation-specific (Boff and Lincoln, 1988; Christ, 1975; Stokes et al., 1990; Weitzman, 1985). Situations where color coding may be particularly useful for drivers include warning the driver of a hazardous event (e.g., activating an amber or red telltale on a primarily a blue-green display), facilitating visual search, and perceptually grouping similar information.

Based on these considerations, the color recommended for the CAMP visual alert display shall be yellow, orange, yellow/orange, or amber. The color red is not recommended for the visual crash alert because of the potential color association with a vehicle system (especially a brake system) failure.

The color for the CAMP visual alert display shall be yellow, orange, yellow/orange, or amber. (10)

Contrast

Contrast refers to the difference between the luminance of a symbol and the luminance of the symbol's background. Luminance refers to the amount of light reflected by or emitted from a surface. For the automotive HUD, symbol luminance refers to the light emitted from the HUD image source which is ultimately reflected from the windshield, as measured after the final reflection with the windshield (e.g., from the eye box of the HUD). There are many definitions and formulas for contrast (see Boff and Lincoln (1988) for examples). The formula used in the requirement below is the ratio of the symbol luminance to the symbol background, that is,

Contrast Ratio = (Luminance Image ÷ Luminance Background): 1

Since a HUD is translucent or "see-through," the value of Luminance Image is the sum of the real-world background luminance and the symbol luminance.

During daytime driving, the critical design issue with respect to display contrast is being able to generate enough luminance to meet minimum legibility requirements. Failure to meet daytime symbol contrast objectives will mean that the display may not be visible under some conditions, many of which may be transitory or short-lived. During nighttime driving, the critical design issue is to ensure that the display is not so bright that it becomes a discomfort and/or disability glare source to drivers, particularly for older drivers. This suggests that a luminance mode mechanism should be provided. This refers to some mechanism (e.g., a day/night light sensor) by which the different ranges of display luminance are activated (e.g., daytime and nighttime luminance ranges). This mechanism is typically headlight-based (i.e., no headlights=daytime mode, headlights=nighttime mode) and/or luminance day/night sensor-based.

Sanders and McCormick (1987) suggest that any warning light should be twice as bright as the immediate background. Older drivers generally have less contrast sensitivity than younger drivers. Thus, the requirement specified below assumes that, all other factors being equal, contrast values that meet the legibility needs of older drivers will always meet the legibility needs of younger drivers.

FMVSS and ISO standards also need to be considered. Currently, four automotive displays (high beam indicator, turn signals, seat belt telltale, and the brake telltale) need to be visible under all driving conditions (whenever the underlying condition is present). A precise definition of "visibility" compliance is not provided. Furthermore, the driver must not be able to dim these four displays (inadvertently or otherwise) to a level that is invisible. This requirement should apply equally well to FCW system crash alerts.

The minimum contrast ratio for the CAMP visual alert display should be 2:1.

The driver shall not be able to dim the CAMP visual alert display (inadvertently or otherwise) to a level that is invisible.

A daytime and nighttime display luminance mechanism shall be provided. (11)

4.2.5 What Non-Crash Alert FCW-Related Information Should be Provided to the Driver?

Primarily visual displays are likely to be involved in providing the driver non-crash alert FCW-related information (i.e., system malfunction and system limitation conditions). This section provides a general discussion of human factors considerations for this type of information, without a detailed discussion of human factors symbol design considerations (e.g., symbol contrast, height, width-to-height ratio, strokewidth-to-height ratio, spacing, font, color). Overall, these displays should be designed with the goal of ensuring that the driver can obtain the relevant information in a timely ("at-a-glance") and effective manner (i.e., without errors). In addition, the design goals of ensuring international drivers are accommodated is an important consideration.

4.2.6 System Malfunction

The *system malfunction* state for a FCW system refers to a mechanism by which the driver can be informed that the FCW system is not working properly and needs service. For example, this state is attained if, for whatever reason, the FCW system crash alerts are not functioning properly. In this case, it may be advisable to allow the drivers diagnostic capability for testing the visual and auditory FCW crash alerts. Since drivers may potentially change their behavior when driving with versus without a FCW system, this information is of high priority and must be clearly conveyed to the driver (irrespective of the form or modality of the information). A brief, momentary auditory tone should be used to indicate the onset of the FCW system malfunction condition. In addition, depending on the complexity of the malfunction information, accompanying text messages may also become advisable. Any FCW system malfunction information should remain displayed until the underlying system malfunction conditions are no longer present. Furthermore, diagnostics information at vehicle-start up should allow drivers to determine whether or not the visual displays associated with the FCW system malfunction are functional.

A FCW system malfunction (e.g., a crash alert display failure) shall be visually indicated in a clear, continuous fashion whenever the underlying malfunction conditions are present.

A brief, momentary auditory tone shall be used to indicate the onset of the FCW system malfunction which should be distinctly different from the CAMP non-speech tone used for crash alert purposes.

Upon application of vehicle power (i.e., during vehicle start-up when the vehicle displays briefly flash) the FCW system malfunction visual displays shall be displayed in a manner which allows drivers to clearly determine whether these displays are functional. (12)

4.2.7 System Limitation Condition

The *system limitation* condition for a FCW system refers to a mechanism by which the driver can be informed that the FCW system, although not in a system malfunction state, is not currently working properly, at full capability, and/or being used with design intention. This may occur under a variety of conditions, including under adverse weather conditions. Since drivers may change their behavior when driving with the FCW system in a system limitation condition, this information is of high priority and must be clearly conveyed to the driver (irrespective of the form or modality of the information). A brief, momentary auditory tone should be used to indicate the onset of the FCW system limitation condition. In addition, depending on the nature of the system limitation (e.g., the frequency and duration), accompanying text messages may also become advisable. Any FCW system limitation information should remain displayed until the underlying limitation conditions are no longer present. Furthermore, diagnostics information at vehicle-start up should allow drivers to determine whether or not the visual displays associated with the FCW system limitation are functional.

A FCW system limitation condition shall be visually indicated in a clear, continuous fashion whenever the underlying system limitation conditions are present.

A brief, momentary auditory tone shall be used to indicate the onset of the FCW system limitation condition, which should be distinctly different from the CAMP non-speech tone used for crash alert purposes.

Upon application of vehicle power (i.e., during vehicle start-up when the vehicle displays briefly flash) FCW system limitation visual displays shall be displayed in a manner which allows drivers to clearly determine whether these displays are functional. (13)

4.2.8 How Should the FCW System Driver Interface be Integrated With Non-FCW Systems?

4.2.8.1 Compatibility With Systems Closely Related to the FCW System

A FCW system provides somewhat similar functionality to the driver as the adaptive cruise control (ACC) system when the driver is not in a cruise control mode. For example, both the ACC and FCW systems are likely to provide the driver many of the same types of information, including driver alerts (discussed below), distance adjustability/settings, and system malfunction/limitation information. A notable functionality difference between ACC and FCW systems is that an ACC system might provide the driver continuous display of cruise speed information.

However, there are also a number of important differences between ACC and FCW systems. First, the nature of any adjustable alert criterion is likely to be fundamentally different across the ACC and FCW systems. The time headway criterion associated with ACC is not likely to play any dominant role in any FCW crash alert timing approaches. Second, the range of target types which will elicit crash alerts to the driver may be different across ACC and FCW systems. The ACC system is specifically designed to track a lead vehicle target, whereas a FCW system is designed to avoid/mitigate rear-end crashes. Third, while the ACC system will control the velocity of the vehicle (either via throttle position, transmission shifting, and/or brake application), it is anticipated that initial market introductions of FCW systems will not provide any form of vehicle velocity control.

In light of these differences, if FCW system display space and alerts are shared with an ACC system, drivers need to clearly understand whether or not the ACC or FCW system is activated, since this information may have implications for appropriate driver behavior (e.g., braking judgments) when encountering a slowing lead vehicle which may be a rear-end crash threat. More generally, these differences suggest any integration of ACC and FCW systems with respect to the driver interface (e.g., using a common, shared alert) need to be carefully understood from a compatibility perspective. For example, one possible ACC alert is to warn the driver if they have exceeded the maximum braking deceleration authority of the ACC system. Since this type of ACC system alert may be largely consistent with the meaning intended by a FCW system alert (i.e., a collision may occur unless evasive control action is taken), the use of a 1-stage alert for both ACC and FCW systems may be promising from a customer education, simple “mental model” perspective.

In addition, careful consideration should be given to the possibility of sharing reconfigurable display space and auditory alerts to present both ACC and FCW system information. An equally important side-effect of this information integration is the amount of valuable display space saved and the amount of visual clutter reduced in the driver’s forward view relative to displaying this same set of information in a non-integrated fashion.

In designing a complete set of FCW system displays and alerts, the overall design goal should be to ensure that international drivers can easily identify and intuitively understand the information displayed, and appropriately act in a timely (“at-a-glance”) and effective manner in response to this information. A possible strategy for attaining this goal may be presenting ACC- and FCW-related information in an integrated fashion.

4.2.8.2 Compatibility With Systems Not Closely Related to the FCW System

Overall, a design goal to ensure the integration of the FCW system (and perhaps, further integration with ACC) does not compromise other types of information conveyed to the driver, whether it be conventional driver information (e.g., radio, climate control) or more advanced driver information (e.g., navigation/route guidance, night vision). With respect to the latter type of information, of particular concern is ensuring FCW systems and other collision warning systems (e.g., backing, side, and intersection warning systems) are appropriately integrated so that when a crash alert (or alerts) occurs, the driver can respond appropriately in a timely and effective fashion (without making errors) to the appropriate collision threat. Other potential vehicle integration issues include muting certain vehicle systems which generate significant interior noise and competing auditory information to the driver (e.g., stereo system,) during the presentation of crash alerts in order to ensure the driver can hear the auditory alert.

4.3 Alert Zone Boundaries

An obstacle is any fixed or moving object that is in the anticipated path of the subject vehicle. The classes of obstacles considered in these performance specifications are other vehicles such as motorcycles, large trucks, cars, and vans. Other possible obstacles are not considered explicitly in these minimum functional requirements and recommendations. Some examples include fallen tree limbs, pedestrians, pedacyclists and large animals. An FCW system that satisfies these requirements may also help prevent or mitigate collisions with these objects.

A major consideration in the FCW requirements development under the project was to define the boundaries relative to the SV within which POVs should be considered as potential crash threats. Figure 4-4 depicts a simplified geometric model of a FCW system sensor’s field-of-view (i.e. Coverage Zone). No explicit assumptions are made regarding the full shape and size of the Coverage Zone of the system. Within the Coverage Zone is the Alert Zone, which is the region where objects may cause an alert.

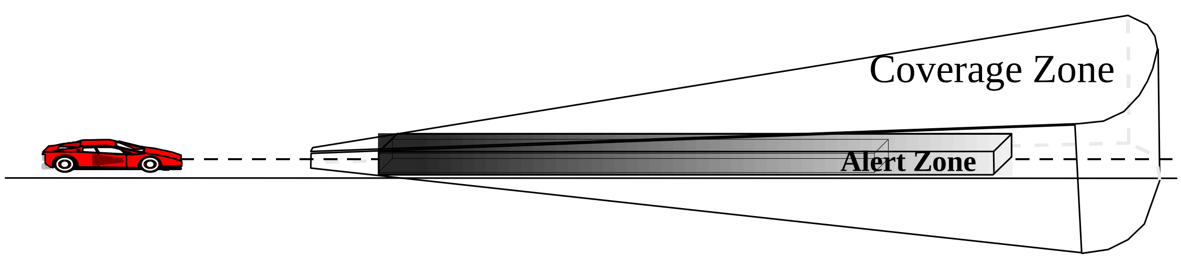


Figure 4-4 Coverage and Alert Zone of a FCW System

The Alert Zone covers the anticipated path of the vehicle. It is a region ahead of the SV where alerts are required if the obstacle meets the crash alert timing criteria. This zone moves smoothly with the vehicle as it changes lanes.

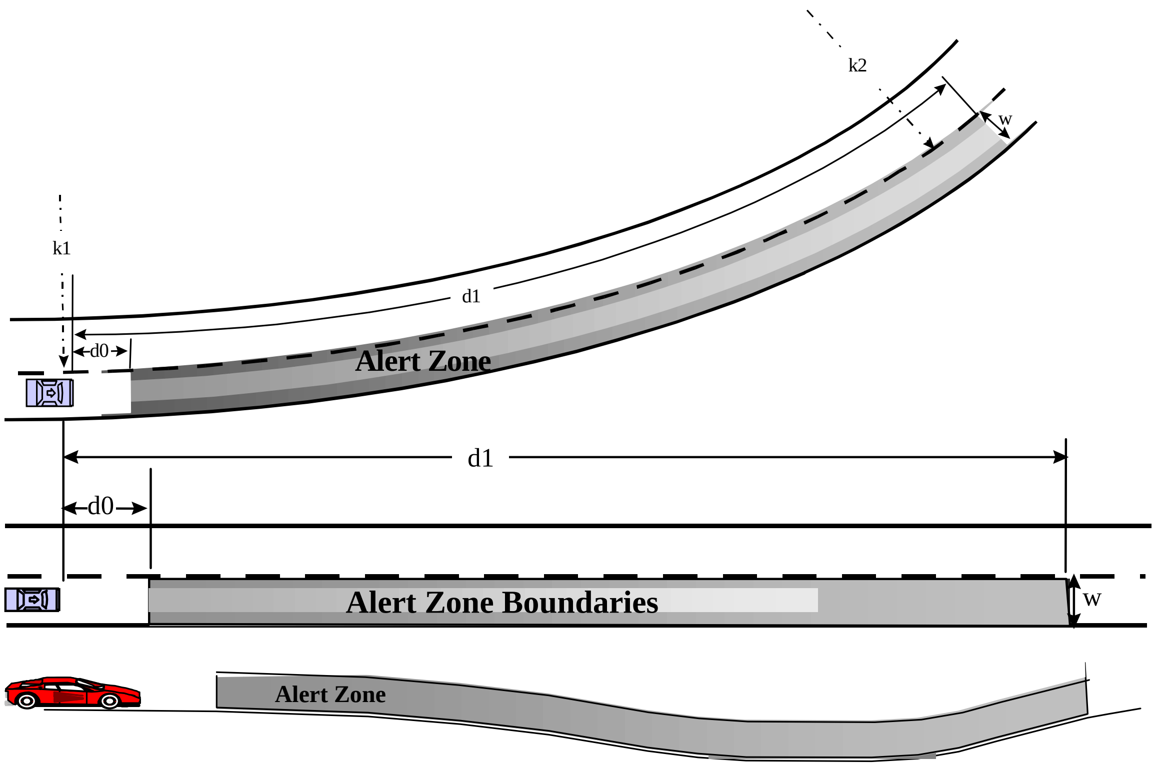


Figure 4-5 Alert Zone Horizontal and Vertical Shape and Size

As shown in Figure 4-5, the horizontal dimensions of the Alert Zone follow the lane that the SV is traveling in while the vertical dimensions follow the road surface. A vehicle is defined to be in the Alert Zone if any part of its rear end is within the lateral, longitudinal and vertical extent of the Alert Zone. The Alert Zone can begin at some distance, d_0, ahead of the SV. The maximum allowable value for this distance is called the *Minimum Longitudinal Alert Zone Extent*. The distance, d_1, to which the Alert Zone must extend, the *Maximum Longitudinal Alert Zone Extent* is defined as the distance at which an alert must occur when the SV approaches a stopped obstacle. For a vehicle in the Alert Zone, alert onset timing requirements from Section 2 apply. Alerts are not allowed to be triggered by objects entirely outside the Alert Zone.

4.3.1 General Requirements for Lateral Characteristics of the Alert Zone

Drivers use a variety of cues to select the path they choose to follow. Lane markings such as stripes and retroreflectors are often the primary indicator of the road direction. The edge of the road, cracks within the road, and even wear marks and oil tracks contribute information that the driver uses to select the path to follow.

Three alternatives have been reviewed extensively by the program participants for the required lateral extent of the Alert Zone. One alternative defines the Alert Zone to cover the width of the lane in which the SV is currently traveling. This approach provides a well-defined border for the Alert Zone as long as the vehicle is clearly traveling in one lane on a road with clear, unambiguous markings. However, this definition becomes more complex when the lane edges are ambiguous, as the SV is changing lanes or when the SV wanders near lane edges.

A second alternative for defining the Alert Zone is to require that it proceed ahead of the SV with a curvature that corresponds to the current turning radius of the SV with a width that is equal to the width of the SV plus some buffer zone. While perhaps easiest to implement, this approach is not thought to correspond well with the suggested mental model of a FCW system.

A third approach for defining the lateral extent of the Alert Zone is to require that it follow the curvature and direction of the road with a width that corresponds to the width of the SV plus some buffer zone. This definition is clear as long as the general direction of the road is unambiguous. It is still ambiguous at forks in the road and as the width of the road changes (e.g., at transitions where the number of lanes changes).

Note that both the first and third of these definitions assume that the heading angle of the SV is small with respect to the direction of the road so that it is reasonable to require that the Alert Zone follow the direction of the road regardless of the heading angle of the SV.

To be consistent with the suggested mental model of a FCW system, the width of the SV should be adequate to provide warnings when a conscientious passenger would consider the anticipated path of the vehicle to be a near miss while not producing nuisance alerts as the SV drives by other vehicles and roadside objects. The minimum zone width is the width of the vehicle and the maximum zone width is 3.6 meters, a standard lane width, with the zone centered on the front of the vehicle.

Since perfect sensing is not possible, the idea of the Alert Zone as two regions is introduced. The inner region is where an appropriate crash alert is required. The second region encompasses the first region and extends further outward. The crash alert is permissible but not required in the outer region. This relates to the concept discussed in the previous section as a timing zone. Figure 4-5 illustrates the region within a region. More details can be found in Chapter 6.

The Alert Zone center should be centered on the front of the SV. (27)

The Alert Zone shall be at least the width of the SV and should not be more than 3.6 meters. (28)

The Alert Zone should follow the curvature of the road in both vertical and horizontal directions. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures and driveways. (29)

4.3.2 Longitudinal Conditions for Alerts

4.3.2.1 Minimum And Maximum Longitudinal Alert Zone Extent

As illustrated in Figure 4-5, the Alert Zone can begin at some distance ahead of the SV. Obstacles closer than this range are not required to cause an alert. The maximum allowable value for this distance is called the *Minimum Longitudinal Alert Zone Extent*.

Consistency with the mental model of a FCW system described in Chapter 2 suggests that a FCW system should always produce a Crash Alert if a ever-vigilant passenger would have enough time to react. Using this philosophy empirical data can be used to set the Minimum Longitudinal Alert Zone Extent. The 5^{th} percentile of driver RT is approximately 0.5 seconds (Olson and Sivak, 1986) and the minimum speed at which rear-end collisions with other vehicles cause significant damage is 10 mph (assuming the POV is stopped and both vehicles have 5 mph bumpers). Using these values leads to a recommended:

Recommended Minimum Longitudinal Alert Zone Extent should be no greater than 2.2 meters. Alerts to objects closer than this are not required. (21)

As illustrated in Figure 4-5, the *Maximum Longitudinal Alert Zone Extent* is defined as the distance at which an alert must occur when the SV approaches a stopped obstacle. The scenarios that most influence this requirement are the distracted and inattentive driver scenarios. Consistency with the mental model of a FCW system described previously suggests that a FCW system always be able to produce alerts consistent with the SV and POV speeds regardless of how fast of slow the SV is moving. However, expert opinion suggests that the sensing technologies available for FCW systems will not be able to satisfy this expectation.

Another approach could be to assume that drivers expect FCW systems to be able to produce alerts consistent with the SV and POV speeds when they are traveling at the highest posted speed limits for roads in the United States. For example, many states have a maximum speed limit of 70 mph. The minimum distance for a crash alert when approaching a stopped POV at this speed using information from Section 4.2.3.1 would mean that the Maximum Longitudinal Alert Zone Extent is 146 meters.

A third approach for determining the required Maximum Longitudinal Alert Zone Extent is to study the potential reduction in harm that FCW systems could provide for alternative ranges. Three studies have addressed the question of the required sensing range of a FCW sensor, based on modeling and simulation of countermeasure performances. Farber and Huang (1995) found diminishing returns in benefits around 300 feet (91m). That study does not address false alarms.

Work at Frontier Engineering (Sanimar et. al. 1997) recommended a 130m working range, based on their modeling and simulation of FCW countermeasure effectiveness. A third study is an elaboration of Farber and Huang (1997) conducted by CAMP (LeBlanc 1997, also see Appendix C). This suggests that diminishing returns in the benefits and increased in-path nuisance alerts occurs at 75 m.

An argument can be made that Sanimar, et. al. 1997 and LeBlanc 1997 provide bounds for a reasonable requirement. This is based on the occurrences of stopped lead vehicles in the respective studies. Sanimar et. al. 1997 assumes that lead vehicle braking begins, essentially, at about a three or four second headway, and that lead vehicle braking occurs at levels of 0.33g and higher. This approach may over-emphasize the lead vehicle stopped case, which pushes required sensor ranges to larger values. LeBlanc 1997 simulated lead vehicle braking with initial vehicle pair headway from a FHWA database constructed from loop detectors on a New Mexico freeway. By definition, this included no stopped vehicles, and the occurrence of lead vehicles stopping before an alert sounds was much less frequent (about 20 to 30%) than the occurrence of lead vehicle stopped cases in the known crash databases (about 70%). Thus, it can be argued that LeBlanc 1997 may underestimate the sensor range. Modeling of FCW performance reported early in the Project, and included here as Appendix C, found that a target sensor that can support warnings at a 75 meter range provides 94% of the benefits of a sensor with unlimited range. That work, however, also states that more accurate modeling of stopped lead vehicle situations might indicate benefits of a longer working range. For this reason, a sensor range of 100 meters will be used as a working requirement for the FCW specification.

The FCW system Alert Zone maximum longitudinal extent should be at least 100 meters in front of the SV. Alerts to POVs beyond this distance are not required. (22)

The Crash Alerts shall be before the POV distance is "too late" and not before the distance is "too early" as defined by the criteria for causing alerts. (See Section 4.2.3 and Appendix B) (2, 15, 16)

4.3.2.2 Illustration of POV Locations for Which Alert Onset Should and Should Not Occur

Crash alert onset timing requirements and the Alert Zone requirements and boundaries have been defined (Chapter 4). A diagram is now presented to visualize some of these requirements by describing four regions in which crash alert onset is required, allowed, or not allowed. No new requirements are presented in this section.

The figure shows the Alert Zone in front of the SV. For illustration, a straight road situation is used (recall the Alert Zone follows the road geometry). Assume that a POV, not shown in the figure, is in front of the SV and the SV is either closing or expected to close shortly on the POV. According to requirements, alert onset is required if any part of the POV is inside the Alert Zone and the range to the POV is equal to or less than a "too late" cutoff range. (The "too late" cutoff is the minimum allowed range at alert onset, and is described in Chapter 4, Section 2). The Alert Zone must be at least as wide as the SV and cannot be wider than 3.6 m. Thus if any part of the POV is within Region 1 in the figure, crash alert onset must have already occurred or the alert is too late.

If the POV is entirely outside the Alert Zone, the FCW must not issue an alert based on the POV. In the figure, this corresponds to Region 2. Alerts issued to POVs entirely in this region are out-of-path nuisance alerts.

If the POV's lateral position, relative to the SV, puts in inside the Alert Zone, but the POV is at a distance greater than either the "too late" cutoff, an alert should not occur. This is Region 3 in the figure. Alerts triggered to the rear-end of a POV in this region is an in-path nuisance alert.

If part of the rear end of the POV is laterally within the maximum allowed Alert Zone lateral extent (3.6m), and it is also in front of the SV and longitudinally closer than the "too early" cutoff range, a crash alert onset may occur. This is Region 4 in the figure. This region represents the tolerance in the alert onset requirements in both the longitudinal and lateral directions.

Note that the requirements involve both the longitudinal and lateral position of the POV, relative to the SV. A POV that barely enters Region 4, the outer portion of the Alert Zone, from an adjacent lane may vary well be at a range that is less than the "too late" cutoff. Yet, alert onset is not required until the POV moves laterally in further, so that it enters the inner portion, Region 1.

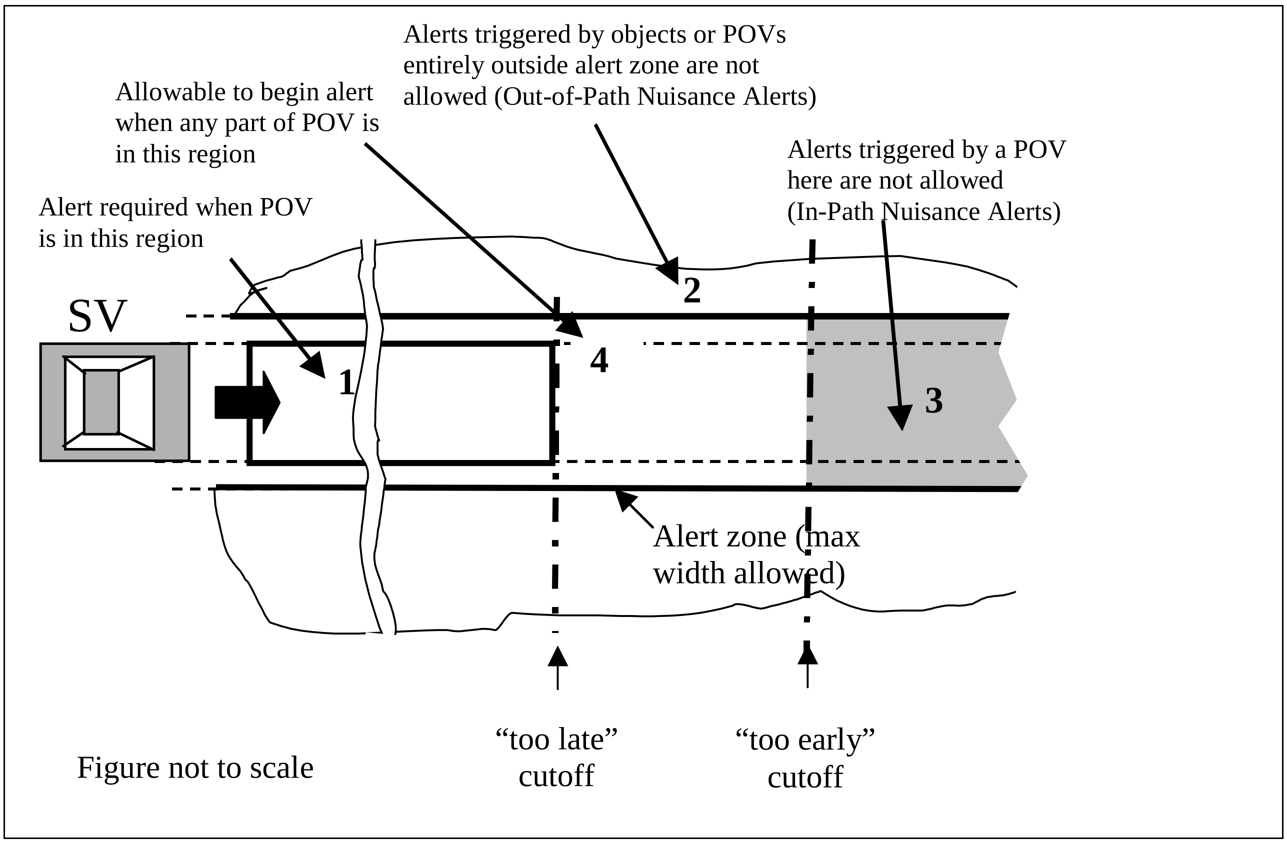


Figure 4-6 POV Locations for Which Crash Alerts are Required, Allowed, and Not Allowed

4.3.2.3 Computer Modeling of FCW Performance Using REAMACS

To help identify and understand the important parameters of countermeasures in rear-end crashes, modeling and simulation work was performed and reported using the computer tool REAMACS (Rear-end Accident Model and Countermeasure Simulation). This work was done early in the Project and included in this final report as Appendix C. The results influenced direction on choosing the Alert Zone maximum longitudinal extent, the need for FCW systems to estimate lead vehicle deceleration, and deepened the understanding of the tradeoffs between providing maximum warning capability while not producing so many nuisance alerts that driver acceptance is negatively affected.

REAMACS computes the potential reduction in relative harm for a countermeasure design, based on a quasi-Monte Carlo analysis of rear-end crash scenarios. REAMACS provides an analytical framework for evaluating such factors as warning algorithms, system range requirements, driver reaction time assumptions, and knowledge of lead vehicle decelerations. A new companion simulation tool was developed during the Project to estimate the relative rates of in-path nuisance alerts for a variety of FCW designs. In-path nuisance alerts are alerts that are triggered by vehicles in the host vehicle's path, but that occur with a timing considered inappropriate by a driver.

Three results in particular impacted the remaining work of the CAMP project:

1. Simulation results suggest it is possible to define a FCW warning algorithm capable of triggering alerts which are timely enough to significantly reduce rear-end crash harm while not producing so many in-path nuisance alerts that drivers reject the system, nullifying any overall benefit.

2. Modeling of FCW performance reported early in the Project, and included here as Appendix C, found that a target sensor that can support warnings at a 75 meter range provides 94% of the benefits of a sensor with unlimited range. That work, however, also states that more accurate modeling of stopped lead vehicle situations might indicate benefits of a longer working range.

3. Information about a lead vehicle's deceleration level can improve the performance of a FCW system. A FCW algorithm using this information can achieve higher potential reduction in relative harm for the same incidence of in-path nuisance alerts than is achievable with an algorithm that does not use lead vehicle deceleration information.

The modeling work used assumptions based on the best available information at the time. That data did not include either the human factors studies of Chapter 3 or the Adaptive Cruise Control (ACC) Field Operational Test results (Fancher et. al., 1998).

4.4 Requirements Induced by Crash Scenario Analysis

As mentioned previously, the primary objective of these minimum functional requirements is to define requirements that will result in FCW systems that satisfy driver expectations. One of those expectations is that FCW systems will help avoid or mitigate crashes without annoyances. To aid in developing requirements that satisfy this objective the Crash Scenarios from Chapter 2 were analyzed. This section reports the results of that analysis.

From each scenario a set of performance goals are derived. For most of these FCW system design goals, limited empirical data are available, so expert judgment played a significant role in defining the requirements. Where possible the results of computer simulations, driving simulator studies, test track experiments and field trials were reviewed to support the decisions.

The FCW System Functionality chapter documents the process used to define the set of crash scenarios considered most significant in the derivation of FCW system performance requirements. Table 4-1 contains a prioritized list of those scenarios from the FCW System Functionality chapter that are relevant to FCW systems. The numbers in the first column are scenario designations from the “44 Crashes” report. (Recall that the column headings “functional years lost” and “direct cost” are, respectively, indices of human injury and direct economic costs of the crashes.) These relevant crash scenarios satisfy three conditions. First, they are observable by a FCW system. Second, a warning would help a driver avoid or mitigate an impending collision. Third, these crash scenarios have high frequency and severity.

Table 4-1 Prioritized List of Relevant Scenarios Based on Functional Years Lost

Number	Name	Frequency (%)	Functional years lost (%)	Direct Cost (%)
62	Inattentive rear-end	12.0	4.9	10.2
56	Distracted rear-end	2.0	1.7	1.9
78	Visibility rear-end	2.0	1.6	1.7
66	Aggressive driver rear-end	1.5	0.5	1.1
52	Tailgate	1.0	0.3	0.8
80	Lane change (cut-in) rear-end	1.0	0.2	0.5

This section summarizes the important characteristics from each of these relevant crash scenarios. It also adds to the previous work by:

- Listing the key characteristics of each scenario that influence the requirements for FCW systems,
- Explaining the characteristics that distinguish each scenario from the others
- Listing a set of possible functional and performance requirements that could be induced from the key characteristics and distinguishing characteristics

It is important to note that the suggested requirements in this section are considered to be ideal. They may not be technically feasible and/or may not result in a driver-acceptable balance between adequate warning and unacceptable annoyance. Section 4.2.4 discusses tolerances for deviations from this ideal.

The following descriptions refer to the Subject Vehicle and Principal Other Vehicle as defined in the "44 Crashes." The *Subject Vehicle* (SV) is the host vehicle containing the FCW system. The *Principal Other Vehicle* (POV) is the vehicle/obstacle that poses the primary risk of collision.

The scenarios are presented in the rank order from Table 4-1.

4.4.1 Inattentive Rear-End Collision

This scenario corresponds to "44 Crashes" scenario #62. The definition states: "SV, following POV, is not paying attention. POV slows or stops and SV strikes the rear-end of POV." An inattentive driver has chosen "…to direct his attention elsewhere for some non-compelling reason". Inattention may include "unnecessary wandering of the mind, or a state of being engrossed in thought matters not of immediate importance to the driving task" (Treat et al., 1977, p. 202).

For this analysis the following key characteristics of this type of collision are assumed:

- Initially the SV is behind POV at a distance that is not tailgating.
- The SV may be traveling above, below, or at the posted speed limit.
- The driver of the SV is inattentive to the driving task for some non-compelling reason. S/he may or may not have their eyes on the road but his/her reaction time to the precipitating event is slow because of the inattention.
- The POV may be moving at a steady speed, may suddenly begin braking, or may have been stopped for a long time.
- The SV approaches the POV and the driver of the SV does not react in time to prevent a collision with the POV

This scenario is distinct from the distracted driver rear-end scenario in that the reason the driver is not paying attention is "non-compelling." For the purposes of these minimum functional requirements, this is assumed to mean that the driver is not performing a visual or manual task other than driving. This scenario is distinct from all but the distracted driver rear-end crash scenario in that the driver's reaction time to the precipitating event (approaching the POV) is much longer. It is not clear whether the distribution of driver's reaction times to an alert will be longer than for other scenarios.

The functional and performance requirements induced by this scenario are:

The CAMP non-speech tone should be presented so that this sound is perceived to emanate from the forward direction of travel of the vehicle (i.e., the location of the potential crash threat) and from the driver's FCW system. The CAMP non-speech tone should not have the ability to be turned off inadvertently or otherwise. (5)

The FCW system shall generate an Alert for POVs **that are in the Alert Zone, which also meet the other criteria for causing alerts. (See Section 4.2.3 and Appendix B) (14)**

The FCW system shall alert if the POV distance meets the criteria for causing alerts. (See Section 4.2.3 and Appendix B) (17)

The Alert Zone should follow the curvature of the road in both vertical and horizontal directions. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures and driveways. (29)

4.4.2 Distracted Rear-End Collision

This scenario corresponds to "44 Crashes" scenario #56. The definition is "SV following POV is distracted. POV slows or stops and SV strikes the rear-end of POV." For a distracted driver "some event, activity, object or person within his vehicle [or outside the vehicle], compelled, or tended to induce the driver's shift of attention away from the driving task" (Treat et al., 1977, p. 203).

For this analysis the following key characteristics of this type of collision are assumed:

- Initially the SV is behind POV at a distance that is not tailgating.
- The SV may be traveling above, below, or at the posted speed limit.
- The driver of the SV is distracted performing some task that requires visual attention.
- The POV may be moving at a steady speed, may suddenly begin braking, or may have been stopped for a long time.
- The SV approaches the POV and the driver of SV does not react in time to prevent a collision with the POV.

This scenario is distinct from the distracted driver rear-end scenario in that the reason the driver is not paying attention is "compelling." For the purposes of these minimum functional requirements, this is assumed to mean that the driver is performing some visual or manual task other than driving. This scenario is distinct from the others in that the driver may not be looking in the direction of the SV's path or the instrument panel. Because the inattention to the driving task is for a compelling reason, a distracted driver's reaction time to an alert may be slower than that for an inattentive driver. It is, therefore, assumed that the distribution of the perception-reaction times to an alert will be longer than for other scenarios because, unlike other scenarios, the driver may have to turn forward to assess the situation before deciding to brake.

The functional and performance requirements induced by this scenario are:

The CAMP non-speech tone should be presented so that this sound is perceived to emanate from the forward direction of travel of the vehicle (i.e., the location of the potential crash threat) and from the driver's FCW system. The CAMP non-speech tone should not have the ability to be turned off inadvertently or otherwise. (5)

The FCW system shall generate an Alert for POVs that are in the Alert Zone, which also meet the other criteria for causing alerts. (See Section 4.2.3 and Appendix B) (14)

The FCW system shall alert if the POV distance meets the criteria for causing alerts. (See Section 4.2.3 and Appendix B) (17)

The Alert Zone should follow the curvature of the road in both vertical and horizontal directions. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures and driveways. (29)

4.4.3 Visibility Rear-End Collision

This scenario corresponds to "44 Crashes" scenario #78. The definition states: "Visibility is limited. SV, following POV, cannot see that POV has slowed or stopped. SV strikes the rear-end of POV."

For this analysis the following key characteristics of this type of collision are assumed:

- The SV is traveling near or below posted speed limits at a steady speed.
- The POV may be stopped, traveling at a steady slow speed, or may be braking.
- Due to atmospheric conditions, the driver of SV does not see the POV until the SV is too close for the SV to stop without a collision.

In this scenario the lack of visibility may be caused by darkness, snow, rain, fog, spray, or dust in the air.

This scenario is distinguished from the other scenarios by the lack of visibility due to atmospheric conditions. This may mean that even an alert driver would not see the POV until the SV is too close to be able to stop in time to prevent a crash.

The functional and performance requirements induced by this scenario are:

The FCW system shall function in all weather conditions or warn if its operation is limited. (30)

The FCW system shall operate during day, night, sunrise, and sunset conditions or warn if its operation is reduced. (31)

The FCW system may generate an alert when a POV is beyond the distance the driver can see clearly. (32)

4.4.4 Aggressive Rear-End Collision

This scenario corresponds to "44 Crashes" scenario #66. The definition states: "SV is driving aggressively, perhaps too fast. POV has slowed or stopped. SV does not have enough time to stop and strikes the rear-end of POV."

For this analysis there are two conditions considered to be in this category.

- The SV is moving much faster than the prevailing speed of preceding vehicles in the same lane or
- The SV is weaving in an attempt to achieve travel much faster than the surrounding traffic.

For this analysis the following key characteristics of this type of collision are assumed:

- The SV operations include fast accelerations and frequent braking, as well as frequent and/or sudden lane changes.
- The POV is ahead of the SV and may be moving at a steady speed that is at or below the prevailing traffic speed when it suddenly begins braking or it may have been stopped for a long time.
- The SV approaches the POV and the driver of the SV does not react in time to prevent a collision with the POV.

This scenario is distinct from tailgating in that the distances and relative speeds are larger. This scenario is distinct from the distracted and inattentive driver in that there are many rapid maneuvers and the reaction time of the driver to the traffic conditions is faster. This scenario is distinct from the other crash scenarios in that there are more frequent and higher rates of lateral and longitudinal acceleration of the SV.

The functional and performance requirements induced by this scenario are:

The FCW system shall alert if part of the POV encroaches into the Alert Zone. (18)

The FCW system should alert to the nearest POV in the Alert Zone if it meets the criteria for causing alerts. (See Section 4.2.3 and Appendix B) (19)

The FCW system shall generate an alert quickly if the conditions change so that they satisfy the crash alert criteria. (See Section 4.2.3 and Appendix B) (20)

The FCW system Alert Zone shall move smoothly with the SV as the SV changes lanes. (26)

4.4.5 Tailgate

This scenario corresponds to “44 Crashes” scenario #52. The definition is “SV is following POV too closely. POV slows or stops and SV strikes the rear-end of POV.”

For this analysis the following key characteristics of this type of collision are assumed:

- The SV is following behind the POV at approximately the same speed,
- The vehicles may be traveling above, below, or at the posted speed limit.
- The distance between the SV and POV is small, (i.e., the gap between the rear end of the POV and the front end of the SV is insufficient to allow the driver of the SV to respond to prevent significant damage or injury should the POV suddenly brake).
- The POV suddenly applies braking.

This scenario is distinct from all other scenarios except the aggressive driver scenario in that the SV and POV are in closer proximity at the start of the scenario. It is distinct from the aggressive driver scenario in that the close proximity may be maintained for a longer period of time. This scenario is also distinguished from the inattentive and distracted driver scenarios in that the driver of the SV is alert and attending to the driving task.

The functional and performance requirements induced by this scenario are:

The FCW system shall alert if part of the POV encroaches into the Alert Zone. (18)

The FCW system should alert to the nearest POV in the Alert Zone if it meets the criteria for causing alerts. (See Section 4.2.3 and Appendix B) (19)

The FCW system shall generate an alert quickly if the conditions change so that they satisfy the crash alert criteria. (See Section 4.2.3 and Appendix B) (20)

The FCW system Alert Zone recommended minimum longitudinal extent should be no greater than 2.2 meters in front and centered on the SV. Alerts to objects closer than this are not required. (21)

4.4.6 Lane Change Rear-End Collision

This scenario corresponds to “44 Crashes” scenario #80, but in these minimum functional requirements, the definition is changed slightly to better reflect the purpose of this requirement. The revised definition states: "POV moves into an adjacent lane. SV, who is in the lane POV moved into, does not have enough time to slow. SV strikes the rear-end of POV."

For this analysis the following key characteristics of this type of collision are assumed:

- The POV is ahead of and in an adjacent lane to that of the SV.
- The SV may be traveling above, below or at the posted speed limit.
- The POV is going slower than the SV.
- The POV moves into the SV's path and the driver of SV do not react in time to prevent the SV from striking the POV.
- During the maneuver POV may maintain constant speed, accelerate, or decelerate.

This scenario is distinct from all of the other scenarios in that the precipitating event is a lateral maneuver of the POV. This results in another distinction from all but the aggressive driver scenario in that the POV may enter the Alert Zone from the side and at a short range. It may also be going much slower than the SV when this happens.

The functional and performance requirements induced by this scenario are:

The FCW system shall alert if part of the POV encroaches into the Alert Zone. (18)

The FCW system Alert Zone shall move smoothly with the SV as the SV changes lanes. (26)

The FCW system Alert Zone center should be centered on the front of the SV. (27)

The FCW system Alert Zone shall be the width of the SV and should not be more than 3.6 meters. (28)

The Alert Zone should follow the curvature of the road in both vertical and horizontal directions. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures and driveways. (29)

4.5 Nuisance Alert Limits

This section covers the maximum tolerance for nuisance alerts due to objects outside the Alert Zone and the minimum requirement for the probability of detection of a threatening situation due to a vehicle inside the Alert Zone.

The previous sections serve to define situations in which an ideal system should produce an alert and other situations in which an ideal system should not produce an alert. When the actual performance of a system is evaluated in those situations four measures of performance can be defined (Table 4-2). A true positive alert is one that occurs under circumstances in which an ideal system would cause an alert. A false positive alert is one that occurs in situations in which an ideal system would not cause an alert. Here we are particularly concerned with situations in which the system may incorrectly evaluate the position or other characteristics of an object or may incorrectly assess whether the object is in the path of the SV.

Table 4-2 Definitions of Alert Performance Metrics

	Threatening Situation	**Non-Threatening Situation**
Alert Produced	True Positive	False Positive (Nuisance Alert or False Alert)
No Alert Produced	False Negative (Missed Alert)	True Negative

True positives can be defined in terms of the probability of detection. If a threatening situation is presented to the system, the True Positive probability is the conditional probability of an alert given a threatening situation. The False Negative probability is the conditional probability that an alert does not occur given that an ideal system should produce an alert. The measurement of these probabilities must account for the distribution of conditions in which a threatening situation can occur. Thus, real world closing rate alerts can occur either with the lead vehicle stopped or with the lead vehicle moving. Furthermore, if the lead vehicle decelerates its initial distance ahead of the SV will have some distribution. Tests to determine if a system meets the minimum requirements must factor in these considerations.

4.5.1 Out-of-Path Nuisance Alert Tolerances

The following requirements are motivated by the need to keep nuisance alerts at a low level when vehicles travel past objects that are not in their path. Consistency with the suggested mental model of a FCW system as an ever-vigilant passenger would suggest that there should be no alerts in these situations.

However, determining what drivers consider an excessive amount of nuisance alarms for a passenger car application is a formidable challenge. CAMP conducted a pilot survey of six users of the Eaton VORAD Collision Warning System for heavy vehicle applications. In a telephone survey, users were asked to estimate the encounter frequency and crash alert rates for eight different operational scenarios. They received illustrations of each scenario in advance of the telephone conversation. They were also asked to indicate for each scenario the acceptability of the current alert rate. Results indicated the following. First, overall, the encounter frequency and crash alert rate estimates varied widely, possibly in part due to the inherent difficulty in describing a scenario in a very specific fashion (e.g., describing a curve without a curve radius). Depending on the scenario the average estimates ranged from 2% to 88% of encounters would produce an alert. For these same eight scenarios, the alert rates were most often judged “very acceptable” (which was the highest point on a 5-point scale). Consequently, at least for these drivers, it appears these alarms were not perceived as a problem, and indeed a significant portion of the drivers indicated that they actually desired them. Given some of these drivers were averaging close to 3000 miles of driving per week, it seems quite likely these alarms may serve to increase the drivers’ vigilance during long periods of driving. Consequently, although nuisance alarms may be quite acceptable for heavy truck drivers, the extent to which these alarms would be judged acceptable for passenger car drivers, who do substantially less driving, remains largely unclear.

Recently, Lerner et al. (1996a) made a very preliminary attempt to understand the effects of various inappropriate alarm rates on passenger car driver's subjective estimates of alarm noticeability, annoyance, and acceptability. These alarms were presented at random times in the driver's own personal vehicle over a 9-week period, independent of any relevant crash avoidance context (e.g., any threat or object which would trigger a crash avoidance alarm). Two auditory alarms were examined: a rapidly beeping tone (a low fuel aircraft warning) and a "check light" voice warning. When a blinking light occurred concurrently with the auditory alarm (meant to correspond to a "real alarm"), the driver was given $4 for pressing a response button within 20 seconds. When the auditory alarm occurred without a blinking light (mean to correspond to an "inappropriate" alarm), the driver was penalized $1 for pressing the button. Inappropriate alarm rates evaluated for the tone included 1 alarm every 0.25 hours, 1 alarm every 1 hour, 1 alarm every 4 hours, and 1 alarm every 8 hours, respectively. Only the 1 alarm every 1 hour conditions were evaluated for the voice condition. The real alarm rates depended on the number of hours of driving per week per subject, which are not reported. However, drivers were recruited under the assumption they drive at least 8 hours per week, and they did experience 3 real alerts during their first 8 hours of driving per week (i.e., 1 real alarm every 2.7 hours during the first 8 hours of driving per week).

Subjective ratings for alarm noticeability did not differ across conditions, whereas annoyance (and *un*acceptable) ratings for the tone were relatively higher in the highest inappropriate alarm rate condition (1 alarm every 0.25 hours) relative to the remaining inappropriate alarm alert rate conditions (which did not differ). Voice alarms were found more annoying than tone alarms, and are not discussed here (see Section 4.2.4). These results would seemingly suggest that an inappropriate alarm rate of 1/hour (in the context of the real alarm rate examined) might be a starting point for deciding on acceptable inappropriate alarm rates. Unfortunately, the extent to which a "real alarm" in a crash avoidance context would offset driver's concerns about inappropriate alarms, and the extent to which a meaningful inappropriate alarm would be considered acceptable, are left largely unaddressed.

In practice, the requirements could be stated in terms of the number of nuisance alerts permissible if an SV is driven through an instance of the scenario a number of times. Different numbers could be specified for driving past the objects on a straight road, on a curved road, and at the transition between a straight and curved road segment for the following two reasons. First, it is more difficult to avoid nuisance alerts on curves and much more difficult to avoid them at the transition between a straight and curved road segment. Second, most driving is done on straight roads so FCW systems will be exposed to stationary objects on these roads much more often than on curves or at transitions between straight and curved road segments.

The following suggested requirement is presented as the current best judgment of the CAMP participants. This requirement was refined using results from human factors studies and expert guidance that was evaluated during the project. The suggested acceptable alert rate for out-of-path nuisance alerts is less than one alert per week for a typical representative sample of driving conditions. Horowitz (1986) estimated that the average U.S. driver covers 201 miles per week. This requirement, like the alert timing requirements, applies to

- alerts given by a 1-stage FCW system with any driver-adjustable timing settings at the minimum (latest, closest) setting, and
- the most imminent alert given by a multiple-stage alert FCW system, with any driver-adjustable timing settings at the minimum (latest, closest) setting.

The recommended acceptable nuisance alert rate for crash warnings due to objects outside of the Alert Zone should be less than one alert per week when the SV is presented with a representative sample of driving conditions. If the FCW system has multiple stages of alerts, this requirement applies only to the most imminent alert. If the FCW system allows driver-adjustable alert timing, this requirement applies only to the minimum (latest, closest) setting. (36)

It is not known whether drivers' tolerance of nuisance alerts will depend on their perception of the source of the nuisance alert. For example, will drivers be more tolerant of a nuisance alert that occurs at the same location on their daily drive to work? Will drivers recognize when nuisance alerts occur in particular traffic situations, and have a different tolerance to those alerts? If indeed driver tolerance to nuisance alerts is later found to depend on characteristics of the situation, an improved requirement set would consider these differences.

Finally, it is noted that no requirements are given here for acceptable levels of nuisance alerts generated by earlier stages in a multiple-alert FCW system, or for earlier settings of a driver-adjustable system. Earlier alert timings are likely to increase the number of both out-of-path and in-path nuisance alerts. These nuisance alerts may create significant negative effects on driver acceptance and effectiveness of FCW systems.

4.5.2 In-Path Nuisance Alerts

In-path nuisance alerts are defined as crash alerts that are in fact triggered by vehicles in the Alert Zone, but are given too early (as described earlier). Such nuisance alerts may result from a FCW system mishandling either simple closing situations, in which a slowed or stopped lead vehicle is in the travel lane, or more complex situations, such as when a faster moving vehicle cuts into the subject vehicle's lane. The suggested allowable in-path nuisance alerts rate is less than one alert per week, for a typical representative sample of driving conditions.

The recommended acceptable nuisance alert rate for crash warnings due to object in-path of the Alert Zone should be less than one alert per week when the SV is presented with a representative sample of driving conditions. If the FCW system has multiple stages of alerts, this requirement applies only to the most imminent alert. If the FCW system allows driver-adjustable alert timing, this requirement applies only to the minimum (latest, closest) setting. (37)

The remarks made in the previous section regarding requirements to address earlier stages or driver settings, or for different types of nuisance alerts, also apply here.

4.6 Requirements Induced by Operational Scenarios

While the purpose of a FCW system is to provide warning information to the driver when confronted by a relevant scenario, the response of the system to other common, non-crash operational scenarios is also important. Chapter 2 documents the definition of a set of operational scenarios considered significant in the derivation of FCW system performance requirements. These operational scenarios are used to modify the functional requirements based on the relevant crash scenarios. The operational scenarios also generate additional functional requirements.

The objective of the set of requirements generated in this document is to characterize a FCW system that meets the assumed expectations of a driver. Therefore the requirements must not depend on the sensing technology used by the FCW, since a driver is not expected to tailor their expectations to the type of sensor employed. Also, the FCW system should signal the driver if atmospheric conditions, rain, snow, fog, etc., cause it to not respond to objects properly at its designed distance. Given that some technologies are able to detect objects beyond the distance that the driver can see clearly, the system is allowed to produce an alert when the driver's vision is limited by lack of light or weather conditions. The FCW system is required to respond to the nearest vehicle in the Alert Zone regardless of other traffic. This includes situations where the other vehicle is a motorcycle that is traveling behind a larger vehicle such as a car, van, or truck. The system should not over look a motorcycle or small a vehicle that is in the Alert Zone when there are larger vehicle on ether side of the Alert Zone at approximately the same distance. FCW systems should not confuse large objects in both adjacent lanes at the same distance with a single object in the same lane as the FCW system.

This section provides brief definitions of the operational scenarios. It also adds to the previous work by:

- Listing the key characteristics of each scenario that influence the requirements for FCW systems
- Explaining the characteristics that distinguish each scenario from the others
- Listing a set of functional and performance requirements that could be derived from the key characteristics and distinguishing characteristics

It is important to note that the suggested requirements in this section are considered to be ideal. They may not be technically feasible or result in a tolerable balance between adequate warning and unacceptable annoyance. Section 4.2.4 discusses tolerances for deviations from this ideal.

It is assumed that a high incidence of nuisance alerts will erode driver confidence in a FCW system, and eventually lead drivers to modify their reactions to appropriate warnings. Such actions, if they occur, will degrade the overall system effectiveness to assist drivers in avoiding or mitigating crashes. Nuisance alerts are defined to be warnings given by a FCW system when an object is present, but not perceived as threatening by a driver. While no quantitative data is publicly available regarding acceptable nuisance alert rates, minimizing their number represents a major challenge to fielding FCW technology given the current state-of-the-art.

Two types of nuisance alerts are considered in these requirements. One type of nuisance alert is due to objects that are actually in the anticipated path of the Alert Zone. A nuisance alert due to these objects may occur if the thresholds for alerts are not commensurate with the evaluation of the driver or if the system does not properly measure the range and speed of the obstacle. Section 4.2.4 discusses minimum requirements for the thresholds for alerts.

Another type of nuisance alert is due to objects that are outside the Alert Zone. An alert may be generated due to these objects if the system does not properly determine the location of the object or if the path prediction is incorrect. This type of nuisance alert is addressed in this section.

4.6.1 Overhead Object

In this scenario, the SV is traveling near posted speed on an urban or a rural road. The SV is approaching an overhead object such as an overpass, suspended bridge, sign or traffic light.

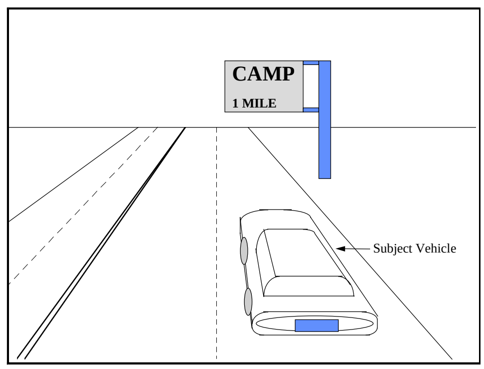


Figure 4-7 Overhead Obstacle

For this analysis the following key characteristics of this type of scenario are assumed:

- The objects are stationary and either discrete or continuous.
- The SV is traveling at a speed consistent with the design of the road.
- The objects are vertically above the actual SV path at a height consistent with AASHTO standard roadway construction and UTCD sign practices.
- The size of the objects may vary drastically (e.g., traffic light to overhead bridge).

This scenario is distinct from the other scenarios in that the object that should not be confused as an obstacle is above the lane in which the SV is traveling. The objects with minimum height that an SV may be driving under at a significant speed (e.g., over 20 kph) may be those associated with parking structures and garages. Parking garages often have a maximum vehicle height of 2.4 meters. Therefore, the Alert Zone should extend to 2.4 meters above the road surface. FCW systems should not produce alerts for objects that do not extend into the vertical extent of the Alert Zone. These include overhead signs, streetlights, traffic lights, and bridges.

The functional and performance requirements induced by this scenario are:

The FCW system Alert Zone vertical extent shall be at least as high as the SV.	**(24)**

The FCW system Alert Zone vertical extent should not be higher than 2.4 meters above the road surface. (25)

The FCW system that generate alerts due to objects outside of the Alert Zone such as cars parked on the side of the road, mailboxes, lamp posts, roadside signs, guardrails, POV in adjacent lane, overhead signs, or bridges shall be counted as an out of path nuisance alert. (34)

4.6.2 Road Surface and Debris

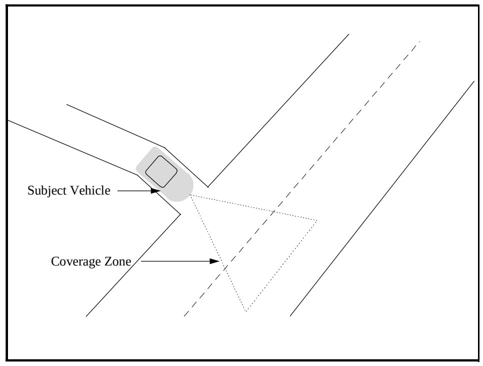


Figure 4-8 Steep Hill

In this scenario the SV is traveling on a sag vertical curve (i.e., where the grade changes rapidly such as at the beginning or end of a hill or at the end of a driveway) so that the road surface is higher relative to the direction of travel than on a level road.

For this analysis the following key characteristics of this type of scenario are assumed:

- There is a sudden upward change in the grade of the road.
- There are irregularities or road surface objects (such as manhole covers) in the lane of the SV.

This scenario is distinct from the other scenarios in that the SV is able to pass over the objects that should not be confused as obstacles.

The functional and performance requirements induced by this scenario are:

The FCW system Alert Zone vertical extent should begin 0.1 meter above the road surface. (23)

The FCW system Alert Zone vertical extent shall be at least as high as the SV. (24)

The FCW system Alert Zone vertical extent should not be higher than 2.4 meters above the road surface. (25)

The Alert Zone should follow the curvature of the road in both vertical and horizontal directions. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures and driveways. (29)

A FCW system that generate alerts due to any part of the road surface regardless of construction materials or in-surface objects shall be counted as an out of path nuisance alert. (35)

4.6.3 Adjacent Lane Traffic

In this scenario, the SV is traveling near posted speed on an urban or a rural street. The SV is approaching a curved section of road wherein a POV is traveling in the adjacent outside lane. Adjacent lane traffic may be on either side of the SV's path or simultaneously on both sides. It may occur on straight or curved road segments. There may be a single vehicle in an adjacent lane or multiple vehicles in the adjacent lanes. Adjacent Lane Traffic can occur simultaneously with traffic in the Alert Zone of the SV.

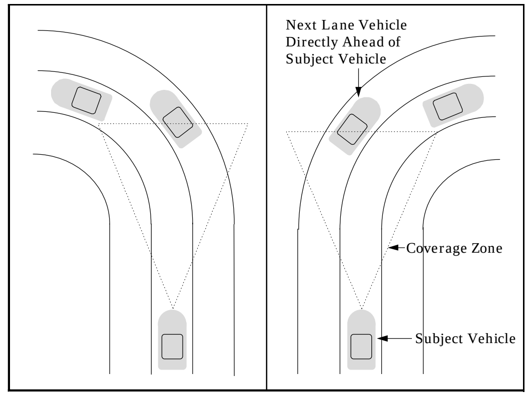


Figure 4-9 Adjacent Lane

For this analysis the following key characteristics of this type of scenario are assumed:

- The curvature could be any value consistent with AASHTO standard urban, rural, or highway roadway construction practices for the speed limit.
- The curvature may be continuously changing (e.g., exit and entrance ramps).
- The non-threatening objects are discrete and moving and may be directly ahead of the SV.
- The speeds of SV and POV are may be significantly different if the POV is in a slow moving lane.

This scenario is distinct from the other scenarios in that the object that should not be confused as an obstacle is moving and may be directly ahead of the SV even though it is not in the same lane as the SV.

Possible functional and performance requirements that could be induced from this scenario are:

The Alert Zone should follow the curvature of the road in both vertical and horizontal directions. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures and driveways. (29)

The FCW system that generate alerts due to objects outside of the Alert Zone such as cars parked on the side of the road, mailboxes, lamp posts, roadside signs, guardrails, POV in adjacent lane, overhead signs, or bridges shall be counted as an out of path nuisance alert. (34)

4.6.4 Adjacent Vehicles

In this scenario, the SV is traveling near posted speed on straight urban or rural street and approaches two large trucks traveling in the right and left adjacent lanes. No other vehicles are traveling in the SV path between the SV and the two large trucks.

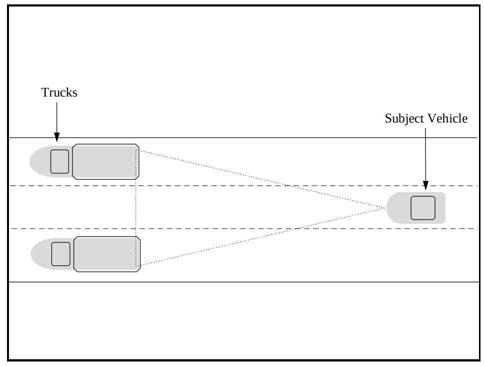


Figure 4-10 Adjacent Vehicles

For this analysis the following key characteristics of this type of scenario are assumed:

- The speeds of SV and POV are similar.
- The SV approaches and then passes between the POVs.
- The size of the POVs is large.

This scenario is distinct from the other scenarios except the Dense Clutter Scenario in that there is no object directly ahead of the SV. This scenario is similar to the Greater Size and Equal Distance. Each has vehicles in the adjacent lanes but only one has a vehicle in the Alert Zone that should cause an alert.

Possible functional and performance requirements that could be induced from this scenario are:

The FCW system Alert Zone shall be the width of the SV and should not be more than 3.6 meters. (28)

A FCW system that generate alerts due to any part of the road surface regardless of construction materials or in-surface objects shall be counted as an out of path nuisance alert. (35)

The FCW system that confuses large POVs in both adjacent lanes at the same distance as a single POV in the same lane as the SV shall be counted as an out of path nuisance alert. (40)

4.6.5 Roadside Clutter

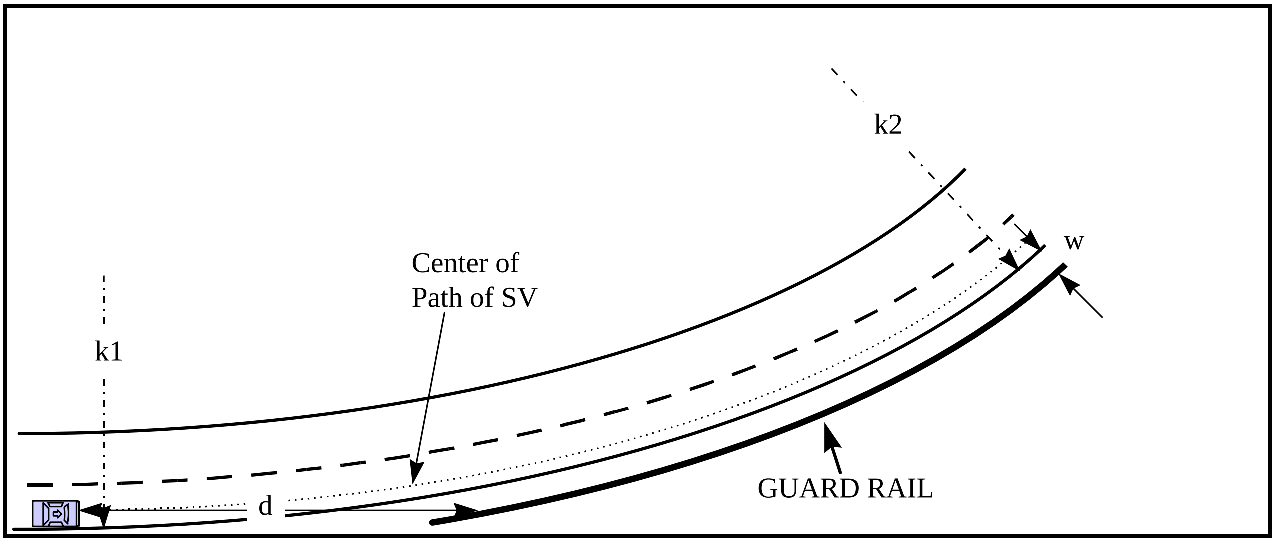


Figure 4-11 Curved Road-Extended Object

Extended objects include metal or concrete guardrails. They may occur on either side of the roadway. They may occur on straight or curved roads and may extend across a transition between straight and curved road segments. Guardrails may include bumpers or twists at their beginnings and ends. In this scenario, the SV is traveling near posted speed on an urban or a rural street. The SV approaches a curved section of road where a guardrail is built close to the lane. This operational scenario is encountered frequently by almost all drivers.

For this analysis the following key characteristics of this type of scenario are assumed:

- The curvature could be any value consistent with AASHTO standard urban, rural, or highway roadway construction practices for the speed limit.
- The curvature may be continuously changing (e.g., exit and entrance ramps).
- On urban and rural roads, guardrails may be very close to the roadway. On highways, there is usually a shoulder between the roadway and a guardrail.

This scenario is distinct from the other scenarios in that the object that the non-threatening object is continuous (e.g., extends a relatively long distance along the roadside) and is stationary.

A possible functional and performance requirements that could be induced from this scenario are:

The Alert Zone should follow the curvature of the road in both vertical and horizontal directions. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures and driveways. (29)

The FCW system that generate alerts due to objects outside of the Alert Zone such as cars parked on the side of the road, mailboxes, lamp posts, roadside signs, guardrails, POV in adjacent lane, overhead signs, or bridges shall be counted as an out of path nuisance alert. (34)

4.6.6 U-Turn in a Median

A limiting case for road curvature is the U-Turn in a Median, shown in Figure 4-12. In this scenario, the SV enters a direction reversal lane (U-turn) in the median of a divided road. The design speed of the curve is much less than the speed limit of the straight road. As the SV enters the reversal lane, the SV driver may decelerate hard to a very low speed or stop before proceeding with the left turn. There may be a large sign or pole outside the curve of the reversal lane. This type of scenario occurs most often in urban areas.

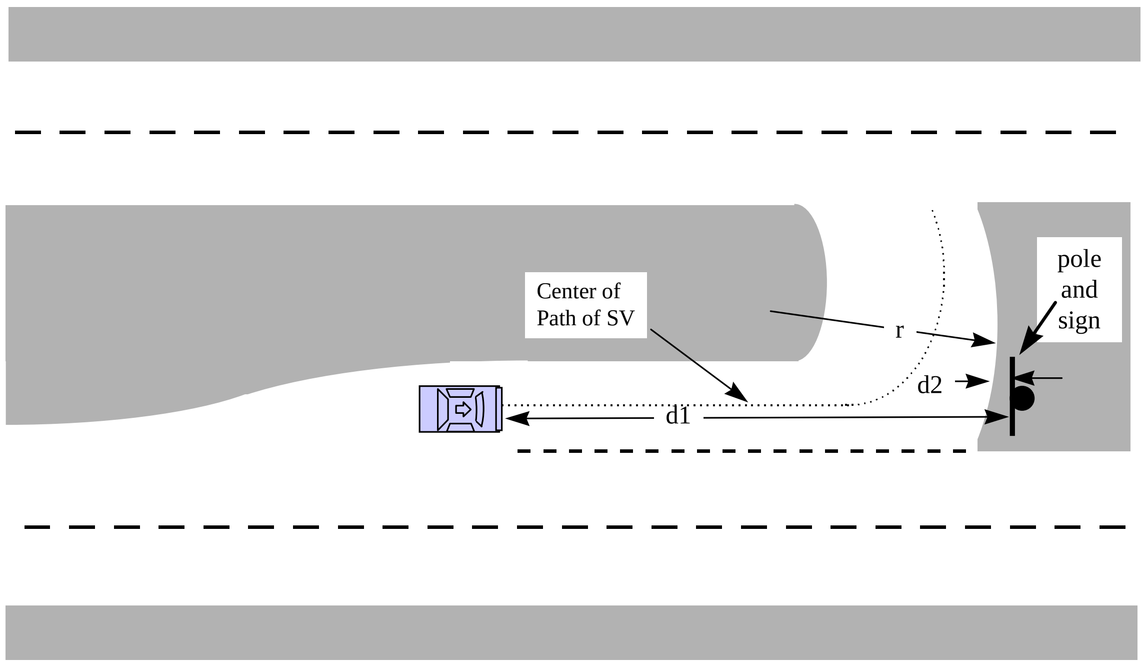


Figure 4-12 Curved Road with Discrete Objects

For this analysis the following key characteristics of this type of scenario are assumed:

- The curvature of the turnabout is small, consistent with a much lower speed than the speed of the straight road.
- The SV may decelerate at anywhere from 0.15g to 0.4g and then travels at low speed once in the curve.
- The objects are discrete and stationary and may be directly ahead of the SV as the SV approaches the turnabout.

- The SV may approach the turnabout at a speed that would be too fast to stop before the obstacle if the SV did not turn.

This scenario is distinct from the other scenarios in that the non-threatening object is discrete (not extending over a long distance) and stationary, and is off the road but may be directly in front of the SV as it decelerates before the turn. It is also distinct from the other curved road scenarios in that the design speed of the U-turn is usually lower resulting in a smaller radius of curvature.

This scenario supports a common working assumption that a driver is likely to be aware of any obstacles ahead of the vehicle if the brakes are already being applied and that alerts under those conditions could be considered a nuisance.

The functional and performance requirement induced by this scenario is:

The FCW system that generate alerts due to objects outside of the Alert Zone such as cars parked on the side of the road, mailboxes, lamp posts, roadside signs, guardrails, POV in adjacent lane, overhead signs, or bridges shall be counted as an out of path nuisance alert. (34)

4.6.7 Dense Clutter Environment

In this scenario, the SV is traveling near posted speed on a narrow urban or rural street where vehicles are allowed to park along the street, or where mailboxes and lampposts are along the road edge. Stopped or parked vehicles may be on the side or shoulder of a road or in adjacent lanes on a multi-lane road. They may be on either side of the path or simultaneously on both sides of the SV. They may occur on straight or curved road segments. There may be a single stopped vehicle or a line of stopped vehicles such as on an urban street or when one lane of traffic is stopped on a highway.

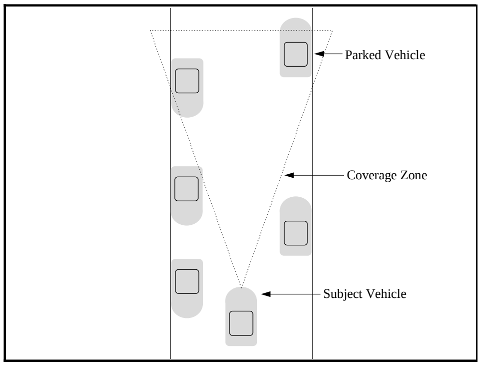


Figure 4-13 Dense Clutter Environment

Other stationary objects that can be beside the road include signs, mailboxes, metal or wooden poles, vegetation, and trash. They may be on either side of curved or straight road segments. Signs and other objects are placed closer to the road on streets with lower speed limits (80 kph and below) that do not have a shoulder. On streets with higher speed limits AASHTO guidelines suggest a 3-meter clear zone.

For this analysis the following key characteristics of this type of scenario are assumed:

- The street may be narrow.

- The objects are discrete and stationary.

- There are a large number of objects per unit distance along the road (e.g., 100 per kilometer).

This scenario is distinct from the other scenarios in that the number and variety of discrete objects is large and they can be very close to the edge of the lane in which the SV is traveling.

Possible functional and performance requirements that could be induced from this scenario are:

The FCW system Alert Zone shall be the width of the SV and should not be more than 3.6 meters. (28)

The FCW system that generate alerts due to objects outside of the Alert Zone such as cars parked on the side of the road, mailboxes, lamp posts, roadside signs, guardrails, POV in adjacent lane, overhead signs, or bridges shall be counted as an out of path nuisance alert. (34)

4.6.8 Diverse Vehicle Sizes

Consistency with the suggested mental model suggests that a FCW should not be confused when there are multiple vehicles that can be observed in the Alert Zone. The following two operational scenarios are included because they represent complex traffic situations that may contribute to missed alerts.

In this scenario, the SV is traveling near posted speed behind a large truck at a long distance. A motorcycle is traveling between the SV and the truck in the SV path. The motorcycle is going slower than the SV as it is approached. This scenario is selected since the FCW system should not overlook the motorcycle as an obstacle as the SV approaches it.

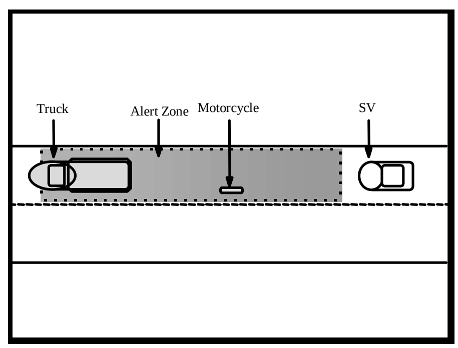


Figure 4-14 Greater Size and Distance

For this analysis the following key characteristics of this type of scenario are assumed:

- The truck and the motorcycle may be traveling at the same or different speeds.
- The motorcycle may be going much slower or at a similar speed to the SV.
- The target sizes are drastically different.

This scenario is distinct from the other scenarios in that there are two vehicles in the same lane as the SV. It is also distinct from all but the Greater Size and Equal Distance Scenario in that it involves a small object that is moving.

A possible functional and performance requirements that could be induced from this scenario are:

The FCW system should alert to the nearest POV in the Alert Zone if it meets the criteria for causing alerts. (See Section 4.2.3 and Appendix B) (19)

The FCW system shall generate alerts when the POV is the rear-end of a vehicle such as a motorcycle, car, van, or truck. (33)

A FCW system should generate alerts due to the nearest vehicle in the Alert Zone regardless of other traffic. This includes situations where the POV is a motorcycle that is traveling behind a larger vehicle such as a car, van, or truck. (38)

4.6.9 Greater Size and Equal Distance

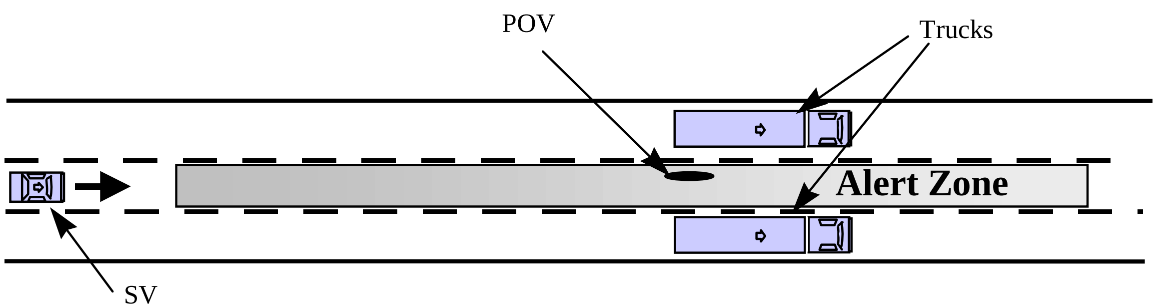


Figure 4-15 Greater Size and Equal Distance

In this scenario, the SV is traveling near posted speed behind a motorcycle at a long distance. The motorcycle is traveling between two large trucks.

For this analysis the following key characteristics of this type of scenario are assumed:

- The speeds of SV, the truck, and the motorcycle may be similar or different.
- The target sizes are drastically different, either in physical or sensor cross section dimensions.

This scenario is distinct from all but the Greater Size and Distance Scenario in that it involves multiple vehicles that are very different in size. It is distinct from the Greater Size and Distance Scenario in that only one vehicle is in the same lane as the SV. A possible functional and performance requirements that could be induced from this scenario are:

The FCW system Alert Zone shall be the width of the SV and should not be more than 3.6 meters. (28)

A FCW system shall not overlook a motorcycle or small vehicle that is in the Alert Zone when there are larger vehicles on either side of the Alert Zone at approximately the same distance. (39)

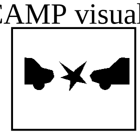
4.7 Requirements Summary

The requirements developed in the previous sections are listed in the following five tables in the order they were presented. Table 4-3 includes the requirements for the driver- vehicle interface. Table 4-4 includes the requirements for the conditions that cause alerts. Table 4-5 includes requirements for Alert Zone boundaries. Table 4-6 includes requirements for the environment around the Alert Zone.

Table 4-3 Driver-Vehicle Interface Requirements

Index	Description	Reference Pages
1	The FCW system shall have at least a 1-stage FCW crash alert. The FCW system may have multiple-stage (e.g., 2-Stage) FCW crash alerts provided additional stages do not reduce the effectiveness of the most imminent alert <u>and</u> all CAMP minimum requirements are met for both a fixed FCW system and for the minimum (latest, closest) setting for a FCW system which provides crash alert timing adjustability. <u>Recommended Approach</u>*: The FCW system should have a 1-stage crash alert*	4-14
2	For a FCW system without crash alert timing adjustability, the crash alert timing shall fall within the “too early” and “too late” onset range cut-offs as defined in Section 4.2.3.1. For a FCW system with crash alert timing adjustability, the minimum (latest, closest) crash alert timing setting shall fall within the “too early” and “too late” onset range cut-offs as defined above. The “too late” cut-off range does not need to be more than 100 meters, for reasons described in Section 4.3.2.1. Note: These cut-offs were based on inputting the following driver behavior parameters into the straightforward kinematic equations described above. (The reader is referred to Chapter 6, Appendix B for a discussion of the domain of validity of these equations.) For the “too early” onset range cut-off, the assumed driver deceleration in response to the crash alert is based on the CAMP RDP equation and an assumed driver brake RT of 1.52 seconds (a 95th percentile driver brake RT). For the “too late” onset range cut-off, the assumed driver deceleration in response to the crash alert was based on the CAMP ADP equation and an assumed driver brake RT of 1.18 seconds (an 85th percentile driver brake RT). <u>Recommended Approach</u>*: The FCW system should be designed with assumed driver behavior input parameters to the kinematic equations described above, as follows. The assumed deceleration in response to the crash alert should be predicted by the CAMP RDP equation, and the assumed driver brake reaction time should be 1.18 seconds (corresponding to an 85th percentile driver brake RT). The domain of validity of this equation is discussed in the text.*	4-24, 4-45

Index	**Description**	**Reference Pages**
3	If the FCW system allows the driver the ability to adjust the crash-alert criterion, the associated control and the crash alert criterion shall be clearly labeled and easily comprehended by the driver. A rotary control, slide, or thumbwheel control should be the type of control provided for this crash alert timing adjustment. This crash alert timing control and the associated control labeling should be consistent with population stereotypes for control/display relationships.	4-25
4	If a single-modality crash alert is implemented, the CAMP non-speech tone shall be used for the alert. If a dual-modality crash alert is implemented, the CAMP non-speech tone and the CAMP visual crash icon (which can be shown on either a HHDD or HUD) shall be used for these auditory and visual crash alerts, respectively. An additional haptic alert may be added to this dual-modality crash alert, however, due to the unresolved implementation and driver behavior issues surrounding this type of an alert, such an approach is not currently advised. *Recommended Approach: The system should have a dual-modality crash alert as specified above, with the exception that the capitalized word "WARNING" should be positioned centered and below the crash alert icon.*	4-28
5	The CAMP non-speech tone shall be used as the auditory crash alert. The CAMP non-speech tone shall be presented so that this sound is perceived to emanate from the forward direction of travel of the vehicle (i.e., the location of the potential crash threat). The CAMP non-speech tone shall not have the ability to be turned off inadvertently or otherwise.	4-30, 4-50, 4-51
6	The intensity of the CAMP non-speech tone should be 75 dBA. Any vehicle systems that generate significant interior noise and competing auditory information to the driver (e.g., stereo system, fan, cellular phone) should be muted during the presentation of the CAMP non-speech tone.	4-31

Index	Description	Reference Pages
7	If a visual crash alert is used as part of a dual-modality approach (which is not required, but recommended), the CAMP visual crash alert icon shall be presented at either a HUD or HHDD location. A LHDD shall not be used for visual crash alert purposes, but may be used for a "post-alert" confirmation display (explained in text above). This LHDD shall also use the CAMP visual crash alert icon. If the visual crash alert is presented at the HHDD location, the alert should be located as follows. To the extent possible, for a 5th percentile (shorter) female driver, the top of the HHDD should be located centerline to the driver such that it is not obscured the steering wheel (or other vehicle structures), and such that it is below the look-down angle to the front hood (i.e., where the hood visually occludes the roadway for this shorter driver). This recommendation generally implies a top-of-dashboard location for the HHDD. Qualitatively, the intent of this objective is to allow shorter drivers the capability of viewing the entire HHDD slightly below the front hood while minimizing any potential obscuration to the forward scene associated with the HHDD. If the visual crash alert is presented at a HUD location, the alert should be located as follows. To the extent possible, the alert should be located centerline to the driver, and at front bumper distance (or about 2.4 m). Furthermore**,** the top of the HUD image should be 4.5° or more below the drivers' line-of-sight, and the bottom of the HUD image should be above the hoodline. Qualitatively, the intent of this latter vertical image location objective is to allow drivers the capability of viewing the HUD image slightly above the front hood.	4-33
8	If a visual crash alert is used, the CAMP visual alert icon shall be used, which is shown to the right:  The CAMP visual alert icon shall be filled (as opposed to outlined). The size of the CAMP visual alert icon should correspond to the total area subtended by a minimum of a 0.34° high by 0.90° wide area. If words are used to supplement the CAMP visual alert icon, the capitalized word "WARNING" is suggested, which should be positioned directly below the icon, and centered relative to the icon? In addition, the height of these letters shall subtend a minimum of 0.26°. _Recommended Approach_: *If provided, the visual crash alert should include both the visual crash alert icon and the word "WARNING" as specified above.*	4-36
9	The flash rate for the CAMP visual alert display should be 4 times per second.	4-36
10	The color for the CAMP visual alert display shall be yellow, orange, yellow/orange, or amber.	4-37

Index	Description	Reference Pages
11	The minimum contrast ratio for the CAMP visual alert display should be 2:1. The driver shall not be able to dim the CAMP visual alert display (inadvertently or otherwise) to a level that is invisible. A daytime and nighttime display luminance mechanism shall be provided.	4-38
12	A FCW system malfunction (e.g., a crash alert display failure) shall be visually indicated in a clear, continuous fashion whenever the underlying malfunction conditions are present. A brief, momentary auditory tone shall be used to indicate the onset of the FCW system malfunction. Upon application of vehicle power (i.e., during vehicle start-up when the vehicle displays briefly flash), the FCW system malfunction visual display(s) shall be displayed in a manner which allows drivers to clearly determine whether this display(s) element is functional.	4-39
13	A FCW system limitation condition shall be visually indicated in a clear, continuous fashion whenever the underlying system limitation conditions are present. A brief, momentary auditory tone shall be used to indicate the onset of the FCW system limitation condition. Upon application of vehicle power (i.e., during vehicle start-up when the vehicle displays briefly flash), FCW system limitation visual displays shall be displayed in a manner which allows drivers to clearly determine whether these displays are functional.	4-39

From each scenario a set of performance goals are derived. For most of these FCW system design goals, limited empirical data was available, so expert judgment played a significant role in defining the requirements. Where possible the results of computer simulations, driving simulator studies, test track experiments and field trials were reviewed to support the decisions.

The following descriptions refer to the Subject Vehicle and Principal Other Vehicle as defined in the "44 Crashes". The *Subject Vehicle* (SV) is the host vehicle containing the FCW system. The *Principal Other Vehicle* (POV) is the vehicle/obstacle that poses the primary risk of collision.

Table 4-4 Alert Zone Timing Requirements

Index	Description	Reference Pages
14	The FCW system shall generate an Alert for POVs that are in the Alert Zone, which also meet the other criteria for causing alerts.	4-50, 4-51
15	The FCW system shall alert before the POV distance is "too late", as defined by the criteria for causing alerts.	4-45
16	The FCW system shall not alert before the POV distance is "too early", as defined by the criteria for causing alerts.	4-45
17	The FCW system shall alert if the POV distance meets the criteria for causing alerts.	4-50, 4-51
18	The FCW system shall alert if part of the POV encroaches into the Alert Zone.	4-52, 4-53, 4-54
19	The FCW system should alert to the nearest POV in the Alert Zone if it meets the criteria for causing alerts.	4-52, 4-53, 4-67
20	The FCW system shall generate an alert quickly if the conditions change so that they satisfy the crash alert criteria.	4-53, 4-53

Table 4-5 Alerts Zone Boundaries Requirements

Index	Description	Reference Pages
21	The FCW system Alert Zone recommended minimum longitudinal extent should be no greater than 2.2 meters in front and centered on the SV. Alerts to objects closer than this are not required.	4-44, 4-53
22	The FCW system Alert Zone maximum longitudinal extent should be at least 100 meters in front of the SV. Alerts to POVs beyond this distance are not required.	4-45
23	The FCW system Alert Zone vertical extent should begin 0.1 meter above the road surface.	4-60
24	The FCW system Alert Zone vertical extent shall be at least as high as the SV.	4-59, 4-60
25	The FCW system Alert Zone vertical extent should not be higher than 2.4 meters above the road surface.	4-60, 4-60
26	The FCW system Alert Zone shall move smoothly with the SV as the SV changes lanes.	4-53, 4-54
27	The FCW system Alert Zone center should be centered on the front of the SV.	4-43, 4-54
28	The FCW system Alert Zone shall be the width of the SV and should not be more than 3.6 meters.	4-43, 4-54, 4-62, 4-66, 4-67
29	The Alert Zone should follow the curvature of the road in both vertical and horizontal directions. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures and driveways.	4-44, 4-50, 4-51, 4-54, 4-60, 4-61, 4-63

Table 4-6 Environment Around the Alert Zone

Index	Description	Reference Pages
30	The FCW system shall function in all weather conditions or warn if its operation is limited.	4-52
31	The FCW system shall operate during day, night, sunrise, and sunset conditions or warn if its operation is reduced.	4-52
32	The FCW system may generate an alert when a POV is beyond the distance the driver can see clearly.	4-52
33	The FCW system shall generate alerts when the POV is the rear-end of a vehicle such as motorcycles, cars, vans, trucks.	4-67
34	The FCW system that generate alerts due to objects outside of the Alert Zone such as cars parked on the side of the road, mailboxes, lamp posts, roadside signs, guardrails, POV in adjacent lane, overhead signs, or bridges shall be counted as an out of path nuisance alert.	4-60, 4-61, 4-64, 4-65, 4-66
35	A FCW system that generate alerts due to any part of the road surface regardless of construction materials or in-surface objects shall be counted as an out of path nuisance alert.	4-60, 4-62

Index	Description	Reference Pages
36	The recommended acceptable nuisance alert rate for crash warnings due to objects outside of the Alert Zone should be less than one alert per week when the SV is presented with a representative sample of driving conditions.	4-57
37	The recommended acceptable nuisance alert rate for crash warnings due to object in-path of the Alert Zone should be less than one alert per week when the SV is presented with a representative sample of driving conditions.	4-57
38	A FCW system should generate alerts due to the nearest vehicle in the Alert Zone regardless of other traffic. This includes situations where the POV is a motorcycle that is traveling behind a larger vehicle such as a car, van, or truck.	4-67
39	A FCW system shall not overlook a motorcycle or small vehicle that is in the Alert Zone when there are larger vehicles on either side of the Alert Zone at approximately the same distance.	4-67
40	The FCW system that confuses large POVs in both adjacent lanes at the same distance as a single POV in the same lane as the SV shall be counted as an out of path nuisance alert.	4-62

4.8 References

American Association of State Highway and Transportation Officials (AASHTO 1995). *Policy on Geometric Design of Highways and Streets: 1994.*

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

Assman, E. (1988). Die Bremsweganzeige im Head-Up Display: Ein Beitrag zur Erhorung der Fahrsicherheit (The indication of braking distance on a head-up display: A contribution to enhance driving safety.). *Zeitschrift fur Verkehrssicherheit (Journal for Traffic Safety)*, 34, 55-59. Cologne, Germany.

Beyerlein, D.G. (1995). New uses and image sources for head-up displays of the future (SAE paper #950960). *Society of Automotive Engineers*. Warrendale, PA:

Boff, K.R. and Lincoln, J.E. (Eds.) (1988). *Engineering data compendium: Human perception and performance.* Armstrong Aerospace Medical Research Laboratory. Wright-Patterson AFB, OH:

Bois, W. (1982). On-board check system with speech synthesis. *IEEE 1982 Workshop on Automotive Applications of Microprocessors*, 88-92. IEEE. New York:

Cole, David E. (1972). Course notes from *Elementary Vehicle Dynamics*. University of Michigan, pp. 1.b.21. September 1971, corrected September 1972,

Eaton VORAD (1996). Advertising brochure.

Fancher, P., Ervin, R., Sayer, J., Hagan, M., Bogard, S., Baraket, Z., Mefford, M., Haugen, J. (1998). *Intelligent Cruise Control Field Operational Test (Final report), Vol. I.* Report No. DOT HS 808 849. Washington, D.C.: U.S. Department of Transportation, National Highway Traffic Safety Administration.

Farber, E. and Paley, M. (1993). *Using freeway traffic data to estimate the effectiveness of rear-end collision countermeasures.* ITS America Annual Meeting

Farber, E., and Huang, M. (1997) Rear-end collision-warning algorithms with headway warning and lead vehicle deceleration information. *Proceedings of the Second World Congress on Intelligent Transport Systems*. III, pp. 1128-1133.

Federal Motor Vehicle Safety Standards (1987). *Motor vehicle safety standard no. 101 controls and displays-passenger car, multipurpose passenger vehicles, trucks and buses.*

Frontier Engineering (1995). *Driver warning system performance specification*. Frontier Engineering. Scottsdale, AZ.

General Motors, (1996). *44 Crashes Version 3.0.* Warren, MI: NAO Engineering Safety & Restraint Center, Crash Avoidance Department.

Graham R., Hirst, S. J. and Carter, C. (1995). Auditory icons for collision-avoidance warnings. *Proceedings of the 1995 Annual Meeting of ITS America*. Washington, D.C.

Graham, R. and Hirst, S. (1994). The effect of a collision avoidance system on drivers' braking response. *IVHS AMERICA*: Atlanta, GA

Grant, B.S. (1994). *Effects of driver alert performance measures on select measure of driver performance and acceptance.* Delco Electronics Corporation oral presentation.

Grant, B.S., Kiefer, R.J. and Wierwille, W.W. (1995). Drivers' detection and identification of head-up versus head-down telltale warnings in automobiles*. Proceedings of the Human Factors Society 39th Annual Meeting*. Santa Monica, CA.

Green, P., Levison W., Paelke G. and Serafin C. (1995*). Preliminary human factors design guidelines for driver information systems*. Office of Safety and Traffic Operations RandD, Federal Highway Administration: McLean, VA.

Hirst, S. J. and Graham, R. (in press). The format and presentation of collision warnings. In Y.I. Noy (Ed.), *Ergonomics and Safety of Intelligent Driver Interfaces*. Lawrence Erlbaum Associates. Hillsdale, NJ.

Horowitz, A. D. (1986): *Automobile Usage: A factbook on trips and weekly travel*. General Motors Research Laboratories, GMR-5351.

van der Horst, A. R. A. (1990). *A time-based analysis of road user behavior in normal and critical encounters*. Doctoral dissertation, Delft University of Technology. Delft, The Netherlands. (Available from the TNO Human Factors Research Institute, PO Box 23, 3769 Soesterberg, The Netherlands.)

International Standards Organization (1996a). *Forward obstacle warning systems*. Latest standardization draft for PWI 14.3*:* ISO/TC 204/WG 14 N 63.3. International Standards Organization.

International Standards Organization (1996b*). Road vehicles: ergonomics applicable to road vehicles.* ISO/TC22/SC13WG8 N 91. International Standards Organization.

Janssen, W. H. and Nilsson, L. (1990*). An experimental evaluation of in-vehicle collision avoidance systems*. Drive II Project V1041: Deliverable GIDS-2.

Janssen, W. H. and Thomas, H. L. (1994). In-vehicle collision avoidance support under adverse visibility conditions. *Proceedings of the 12th Triennial Congress of the International Ergonomics Association.* pp. 179-181. Human Factors Association of Canada. Toronto, Canada:

Kato, H., Ito, H., Shima, J., Imaizumi, M. and Shibata, H. (1992). *Development of hologram head-up display.* SAE Paper #920600. Society of Automotive Engineers. Warrendale, PA.

Kiefer, R.J. (1996). *A review of driver performance with head-up displays.* Paper presented at the Third Annual World Congress on Intelligent Transportation Systems. Orlando, FL.

Landau, F. H. (1995). *Human factors design of collision warning systems*. VERTIS. Toyko.

LeBlanc, David (1997). *Analysis of rear-end collision warning performance metrics using REAMACS.* Crash Avoidance Metrics Partnership.

Lerner, N. D., Decker, D.K., Steinberg, G.V. and Huey, R.W. (1996a). *Inappropriate alarm rates and driver annoyance*. DOT HS 808 533. Office of Crash Avoidance Research, National Highway Transportation Safety Administration. Washington, D.C.

Lerner, N. D., Kotwal, B. M., Lyons, R. D., and Gardner-Bonneau, D. J. (1996b). *Preliminary human factors guidelines for crash avoidance warning devices*. DOT HS 808 342. Office of Crash Avoidance Research, National Highway Transportation Safety Administration. Washington, D.C.

McGehee, D. V., Dingus, T. A. and Wilson, T. (September 1996). *Collision warning effectiveness on the Iowa Simulator: Examination of driver's collision avoidance behavior using a front-to-rear end collision warning display*. Oral briefing to the NHTSA Office of Crash Avoidance.

McGehee, D. M., Mollenahuer M. and Dingus, T. (1994). *The decomposition of driver/human factors in front-to-rear-end automotive crashes: Design implications*. ERTICO. Belgium

MIL-STD-1472D (1989). *Human engineering criteria for military systems, equipment, and facilities*. U.S. Government Printing Office. Washington, D.C.

Nakajima, T., Satoh, H., Kikuchi H., Manakkal R. S., Igarashi R. and Chiang, D. (1996). *Evaluation of driver interface for adaptive cruise control*. ITS America. Washington, D.C.

National Highway Transportation Safety Administration (1996). *Preliminary assessment of crash avoidance systems benefits*. National Highway Transportation Safety Administration: Washington, DC.

Neuman, T.R. (1989). New approach to design for stopping sight distance. *Transportation Research Record 1208*, 14-22.

Nilsson, L., Alm, H. and Janssen, W. H. (1991). *Collision avoidance systems - Effects of different levels of task allocation on driver behavior*. Drive II Project V1041: Deliverable GIDS-3.

Occupational Safety and Health Administration, (1983). *Occupational nose exposure: Hearing conservation amendment.* Federal Register, 48, 9738-9783.

Okabayashi, S., Sakata, M., Furukawa, M., Fukano, J. Daidoji, S., Hashimoto, C. and Ishikawa, T. (1989). *Development of practical heads-up display for production vehicle application* (SAE paper # 890559). Society of Automotive Engineers. Warrendale, PA.

Olson, P.L. (1989). *Driver perception response time*. SAE Paper #890731. Warrendale, PA: Society of Automotive Engineers.

Olson, P.L. (1996). *Forensic aspects of driver perception and response time*. Tucson: Lawyers & Judges Publishing Company, Inc.

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

Robbins, C.K. (1969). *Head-up display (HUD) aiding in car following*. Unpublished master's thesis, Ohio State University, Columbus, OH.

Sanders, M.S. and McCormick, E.J. (1987). *Human factors in engineering and design* (6th ed.). New York: McGraw Hill.

Sanimar, R, Prevallet, V. and Burns, M. (1997). *Mathematical modeling and simulation for forward-looking collision avoidance*. Frontier Engineering.

Saunby, C.S., Farber, E.I. and Demello, J. (1988). *Driver understanding and recognition of automotive ISO symbols.* SAE paper #880056. Warrendale, PA: Society of Automotive Engineers.

Sayer, J.R. (February 18, 1996). *Personal communication*.

Sayer, J.R, and Green, P. (1988). *Driver understanding and recognition of automotive ISO symbols.* SAE paper #880057. Society of Automotive Engineers. Warrendale, PA:.

Serafin, C. (1997). Driver preferences for adjustable distance control labels for an adaptive cruise control (ACC) system. *Proceedings of the Human Factors and Ergonomics Society 41sr Annual Meeting* (pp. 934-938). Human Factors and Ergonomics Society. Albuquerque, NM, Santa Monica, CA.

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

Stapleton, L., Ward, N.J. and Parkes, A.M. (1994). *Behavioral and cognitive impact of night-time driving with HUD contact analogue infra-red imaging.* Paper presented at the XIVth International Conference on the Enhanced Safety of Vehicles (paper 94-S2-O-04). Munich, Germany.

Tan, A. and Lerner, N. D. (1995). *Multiple attributes evaluation of auditory warning signals for in-vehicle crash avoidance warning systems*. DOT HS 808 535. Office of Crash Avoidance Research, National Highway Transportation Safety Administration. Washington, D.C.

Tan, A. and Lerner, N. D. (1995). *Acoustic localization of in-vehicle crash avoidance warnings as a cue to hazard detection*. DOT HS 808 534. Office of Crash Avoidance Research, National Highway Transportation Safety Administration. Washington, D.C.

U.S. Department of Transportation: Federal Highway Administration. (1988). *Manual On Uniform Traffic Control Devices For Streets and Highways (MUTCD).* US DOT FHWA-SA-89-006 HTO-21/2-89(15M)P.

VanCott, H. P. and Kinkade, R. G. (1972). *Human engineering guide to equipment design.* Joint Army-Navy-Air Force Steering Committee.

Watanabe, T., Kishimoto, N., Hayafune, K., Yamada, K. and Maede, N. (1995). *Development of an intelligent cruise control*. VERTIS. Tokyo, Japan.

Weihrauch, M., Meloeny, G.G. and Goesch, T.C. (1989). *The first head-up display introduced by General Motors*. # 890288. Society of Automotive Engineers. Warrendale, PA.

Weitzman, D.O. (1985). Color coding re-viewed. *Proceedings of the Human Factors Society 29th Annual Meeting* (pp. 1079-1083). Human Factors Society. Santa Monica, CA.

Wierwille, W.W. and McFarlane, J. (1991). *Overview of a study on direction-of-motion stereotype strengths for automobile controls.* SAE paper #910115. Society of Automotive Engineers. Warrendale, PA.

Wilson, T.B., Butler, W., McGehee, D.V. and Dingus, T.A. (1997). *Forward-looking collision warning system performance guidelines.* SAE paper #970456. Society of Automotive Engineers. Warrendale, PA.

Woodson, W. E., Tillman, B. and Tillman, P. (1993). *Human factors design handbook.* New York: McGraw Hill.