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The Crash Avoidance Metrics Partnership (CAMP) is a partnership established by Ford and General Motors to undertake joint pre-competitive work in advanced collision avoidance systems. CAMP was established to accelerate the implementation of automotive crash avoidance countermeasures and define pre-competive enabling elements

16. Abstract
In 1996, over 1.8 million rear-end crashes occurred in the United States with approximately 2,000 associated fatalities and 800,000 injuries. Rear-end crashes accounted for approximately 25% of all police-reported crashes and 5% of all traffic fatalities. Forward Collision Warning (FCW) systems are now emerging that provide alerts intended to assist drivers in avoiding or mitigating rear-end crashes.

This report describes activities undertaken by CAMP to define and develop key pre-competitive enabling elements of FCW systems. These elements include the definition of specific crash type(s) that an FCW system should be designed to address, the resulting minimum functional requirements for such a system, and objective test procedures for evaluating the extent to which a particular system design provides the desired functionality. Establishing these key elements will enhance consistent countermeasure system implementation across manufacturers. This will result in improved customer understanding and acceptance and help to accelerate the implementation of FCW systems.

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TABLE OF CONTENTS

CAMP

Crash Avoidance Metrics Partnership

PROGRAM OVERVIEW

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In 1996, over 1.8 million rear-end crashes occurred in the United States with approximately 2,000 associated fatalities and 800,000 injuries. Rear-end crashes accounted for approximately 25% of all police-reported crashes and 5% of all traffic fatalities. Forward Collision Warning (FCW) systems are now emerging that provide alerts intended to assist drivers in avoiding or mitigating rear-end crashes. This project was conducted to define and develop key pre-competitive enabling elements of FCW systems. These elements include definition of the specific crash type(s) that an FCW system should be designed to address, the resulting minimum functional requirements for such a system, and objective test procedures for evaluating the extent to which a particular system design provides the desired functionality. Establishing these key elements will enhance consistent countermeasure system implementation across manufacturers. This will result in improved customer understanding and acceptance and help to accelerate the implementation of FCW systems

This effort focuses on FCW systems designed for light vehicles (passenger cars, light trucks and vans). Taking into account a fundamental understanding of potential countermeasure system technology, specific high frequency and severity crash scenarios were identified. Six relevant situations were selected from a previous analysis which postulates interactions of causal factors and crash outcomes in the form of specific crash scenario descriptions. The underlying assumptions used in the selection process are that the potential threat is observable by line-of-sight sensing from the front of the host vehicle, drivers avoid or mitigate the impending crash by braking only, and that the FCW system operates autonomously within existing infrastructure. The scenarios selected contain the majority of the situations described in the analysis in which one vehicle strikes the rear-end of another as a result of driver error. These situations account for over 16% of the direct costs and over 9% of the functional years lost annually from police reported crashes in the United States. The most common conditions in which rear-end crashes occur are during daylight hours on dry, flat, straight roads under clear atmospheric conditions. The predominant causal factor is driver inattention. While pedestrian and animal crashes may also be mitigated by FCW systems in some instances, these are typically very different scenarios from rear-end crashes and are not considered in the performance requirements set developed. Based on these scenarios, a driver's "mental model" of how an FCW system should perform was developed. This model suggests that the FCW system should behave like an ever-vigilant passenger, producing a crash alert only when a passenger would become alarmed. A set of “operational scenarios” were also defined which describe commonly encountered driving situations that may cause missed or unwanted ("out-of-path nuisance") alerts such as approaching a guardrail on a curve, overhead signs or bridges. In all, six crash scenarios and nine operational scenarios were identified.

Crash alert timing and crash alert modality (auditory, visual and/or haptic) requirements were developed by conducting a series of closed-course human factors studies using a "surrogate target" methodology developed in this program. The "surrogate target" consists of a molded composite mock-up of the rear half of a passenger car mounted on an impact absorbing trailer that is towed via a collapsible beam. The surrogate target provides a realistic crash threat to drivers, yet is able to absorb impacts of up to a 10 mile per hour velocity differential without

sustaining permanent damage. This approach allowed experimenters to safely place naive drivers in realistic rear-end crash scenarios on a proving ground and observe their behavior.

In the first phase of human factors testing, drivers were asked to perform last second braking maneuvers while approaching a slowing or stopped vehicle (surrogate target) without FCW alerts. Drivers were instructed to use either "normal" or "hard" braking to avoid a crash. For each instruction, the point at which drivers chose to begin braking and how hard they actually braked to avoid a crash was found to be a function of closing speed and lead vehicle deceleration rate. Driver’s "hard" braking behavior was then modeled and used as the alert timing criterion for the second phase of testing, which evaluated drivers’ reaction times to a variety of interfaces under surprise and alerted conditions. This reaction time data was then combined with knowledge of driver’s braking behavior to develop a model for the range at which an FCW alert should be given. The resulting alert prompts inattentive drivers to begin braking at a point consistent with the preferred last second "hard" braking judgements observed. This timing criteria provides an alert after most attentive drivers would have started a "normal" last-second braking maneuver, yet soon enough for most drivers to still avoid a crash using "hard" braking. This approach minimizes the number of alerts which drivers perceive as too early ("in-path nuisance" alerts) while maintaining high FCW effectiveness under tested conditions. This model is significantly different from previously developed alert criteria that are based on headway-time or time-to-collision. The difference is attributed to the surrogate target methodology, which is believed to present a more realistic crash threat than previously available. The various interfaces were compared using subjective and objective measures, including driver reaction time. The preferred FCW alert interface consists of a specific non-speech tone (required) and visual icon (recommended, but not required). If included, this icon should be flashed on a "high head-down" display. A steady or flashing head-up display of this same icon may be substituted. A brake pulse haptic alert was also studied, but such an alert is not recommended because of driver response (annoyance / confusion) and vehicle implementation issues (vehicle response under low traction conditions).

Based on the results of the scenario analysis and human factors testing, a set of *preliminary* minimum functional requirements and associated vehicle level objective test procedures were developed. The functional requirements specify the crash alert response of an FCW equipped vehicle in both crash relevant and non-crash operational driving scenarios (i.e., alert too early / too late / no alert). The objective test procedures verify vehicle system level performance with professional drivers. A set of 26 test procedures specify requirements for the test site, instrumentation and execution including pass / fail criteria. These tests are expected to take a total of two to four weeks to execute and are designed to be repeatable across different test sites. These test procedures were validated by executing a subset of five critical scenarios with off-the-shelf laser and radar based FCW systems at the GM Proving Ground in Milford, Michigan and at the Transportation Research Center in East Liberty, Ohio. The scenarios selected for validation were those considered most difficult to execute.

The approach of establishing minimum vehicle-level performance requirements (i.e., what the system should do) contrasts with previous attempts to define specific sensor and processing performance requirements (i.e., how to build the system). These criteria describe the minimum performance of an ideal FCW system from the driver’s perspective. This approach allows countermeasure system suppliers to utilize whatever technology becomes available to best perform the desired function.

The preliminary minimum functional requirements and objective test procedures for FCW systems developed in this project provide a sound framework on which to build. However, there is no claim that these requirements can be met with currently available technology. It is also possible that countermeasure systems which do not meet all of the proposed requirements may still provide drivers with some level of crash avoidance / mitigation benefit. In addition, these results are subject to a number of limitations. Among them are the range of initial conditions evaluated in the human factors testing, the instrumentation quality data used to model the proposed alert timing criteria, and the limited evaluation used to establish the "nuisance alert" exposure rates on which objective test procedure pass / fail criteria are based. All human factors testing was conducted during clear weather daylight conditions on a straight, dry, level road. "Instantaneous" knowledge of lead vehicle behavior (including deceleration) was obtained from on-board instrumentation via vehicle-to-vehicle communications. The crash scenario evaluated was an in-lane approach to a stopped vehicle or a lead vehicle exhibiting constant deceleration levels. While the scenarios evaluated represent the majority of rear-end crashes, further testing is necessary to establish driver acceptance of the proposed alert timing and interface modality requirements under different operating conditions using autonomous sensor data. Among the additional conditions that should be considered are nighttime, bad weather, and non-constant lead vehicle deceleration profiles. Also, true nuisance alert exposure rates are driver dependent. Extensive field operational testing is necessary, at a minimum, to better understand what levels of nuisance alerts are acceptable to drivers.

System Functionality

The purpose of a Forward Collision Warning system is to provide alerts to assist drivers in avoiding or reducing the severity of crashes involving the FCW equipped vehicle striking the rear-end of another vehicle. These alerts should be provided in time to help drivers avoid most common rear-end crashes by braking only, while also minimizing "nuisance alerts" in order to improve driver acceptance. Nuisance alerts are warnings issued in situations that the driver does not perceive as alarming. Nuisance alerts include warnings triggered by objects ahead of the vehicle but outside of the driver’s intended path ("out-of-path" nuisance alerts) and alerts caused by a vehicle in the driver’s intended path in situations not considered alarming by the driver ("in-path" nuisance alerts).

The FCW system is assumed to operate autonomously within existing infrastructure. Proper operation of the FCW system does not require cooperative interaction with other vehicles or the roadway. However, systems may take advantage of common infrastructure features such as lane markings if they are present. The system provides alerts only. It does not attempt to control the FCW equipped vehicle to avoid an impending crash. The system monitors the forward scene and evaluates potential threats. However, the system can only address situations that are observable by line-of-sight sensing from the front of the FCW equipped vehicle.

Balancing system effectiveness against driver annoyance is a key issue in defining the performance characteristics of an FCW function. If the system is required to provide alerts such that all drivers are able to avoid rear-end crashes in all possible situations, the resulting system would necessarily provide alerts to a large number of drivers in situations which they did not consider alarming. The resulting high number of in-path nuisance alerts may cause drivers to ignore the FCW alerts and thus reduce system effectiveness substantially. A high number of out-of-path nuisance alerts will also exacerbate this problem. A more feasible goal is to provide alerts which will assist drivers to avoid most common rear-end crashes by braking only. A consistent "mental model" of how the FCW system performs this task is key to wide spread driver understanding and acceptance. The proposed model is one of an "ever-vigilant passenger", producing alerts only in situations in which a knowledgeable passenger would become alarmed.

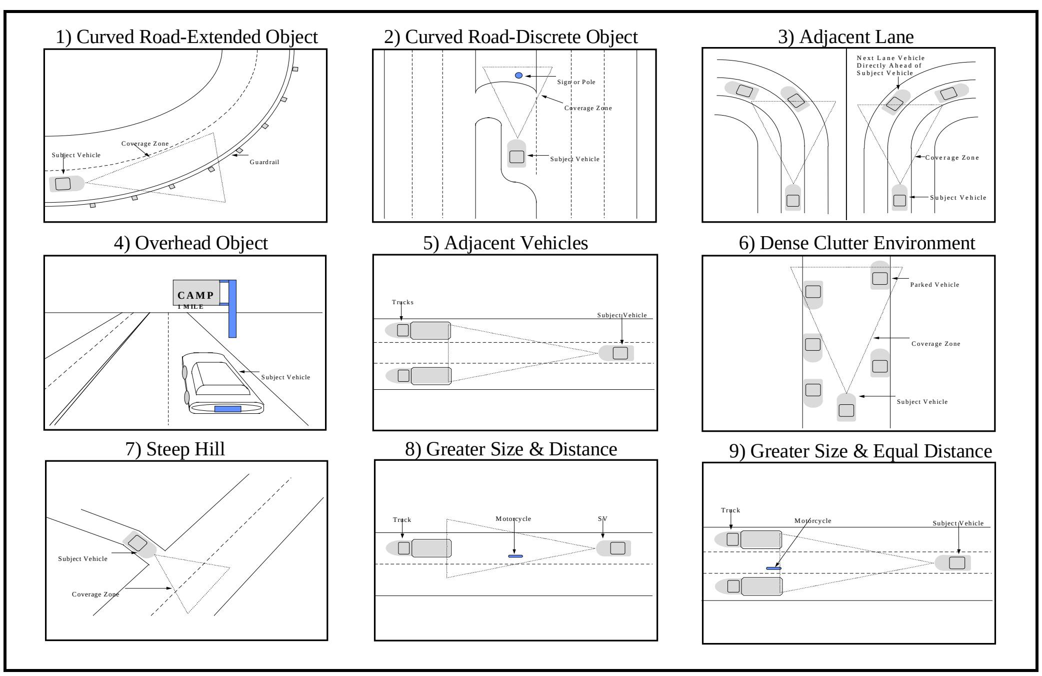
The specific crash problem which an FCW system should address is described in terms of the prioritized list of six rear-end crash scenario descriptions contained in Table 1. These scenarios were selected from previous analysis work ("44 Crashes", Version 3.0, General Motors, January 1997) which combined crash outcome statistics (1991 General Estimates System, 1990 Michigan and 1991 North Carolina police reports) with causal factors (Tri-Level Study of the Causes of Traffic Accidents, Indiana University, Treat, J.R., et. al., 1979). These scenarios were judged to satisfy three conditions. They are observable by the FCW system, a warning may have helped a driver brake to avoid or mitigate the impending crash, and they are high frequency and severity events. In this analysis, severity comprehends both the direct costs of crashes and the functional years lost due to death or incapacitating injury. The most common conditions associated with rear-end crashes are straight roads during the daytime under clear weather conditions. Driver inattention is the major causal factor in these rear-end crash scenarios. It is possible that FCW systems may provide some benefit in other crash scenarios. However, the resulting wide range of operating conditions, pre-crash dynamics and struck objects would drive an unrealistic FCW system specification. Therefore, the scenario set selected was restricted to situations in which one vehicle strikes the rear-end of another as a result of driver error. The six scenarios selected represent 19.5% of all crashes and account for 16.2% of the direct costs and 9.2% of functional years lost from motor vehicle crashes in the U.S. annually.

Table 1 - Prioritized List of Relevant Rear-End Crash Scenarios

Scenario	Frequency (%)	Functional years lost (%)	Direct Cost (%)
Inattentive driver	12.0	4.9	10.2
Distracted driver	2.0	1.7	1.9
Poor Visibility	2.0	1.6	1.7
Aggressive driver	1.5	0.5	1.1
Tailgate	1.0	0.3	0.8
Cut-in	1.0	0.2	0.5

The response of the FCW system in other common non-crash "operational scenarios" is also a key driver acceptance issue. Using the proposed model of a knowledgeable "ever-vigilant passenger", a set of driving scenarios that may cause unwanted or missed alerts was developed. These scenarios include overhead signs and bridges, elements of the road surface (gratings, manhole covers, crosswalk striping) and debris on the road, vehicles in adjacent lanes, roadside clutter (signs, guardrails, mailboxes) and widely varying vehicle sizes in the same or adjacent lanes as depicted in Table 2. These situations also drive FCW system requirements. In both sets of scenarios, the (potentially) FCW equipped vehicle is referred to as the Subject Vehicle (SV) and the vehicle that poses the potential collision threat is the Principal Other Vehicle (POV) .

Table 2 – FCW System Operational Scenarios



Human Factors Studies

The human factors portion of this project defined driver-interface requirements for an FCW system. Effort was focused on when to present crash alerts in an approach situation (i.e., alert timing) and how to present crash alerts to drivers (i.e., auditory, visual and/or haptic alert modality). The goal was to develop an approach to FCW alert timing and modality that would assist drivers in avoiding or mitigating a rear-end crash in a high percentage of situations while not generating alerts in situations drivers perceive as non-alarming.

In order to develop these requirements, it was necessary to collect data on driver braking behavior under controlled yet realistic rear-end crash conditions. Prior to this work, available data on driver behavior in rear-end crash situations has been collected almost exclusively in driving simulators. In this case, an artificial lead vehicle or "surrogate target" methodology was developed that allowed for the possibility of safe, low-speed impacts by an approaching vehicle. This target consisted of a molded composite mock-up of the rear half of a passenger car mounted on an impact-absorbing trailer. A lead vehicle towed the target via a collapsible beam. This combination of impact absorbing target and collapsible tow beam is able to absorb impacts by a following vehicle of up to a 10 mile per hour velocity differential without sustaining permanent damage or deploying the impacting vehicles airbags. The lead vehicle was modified to brake automatically at various constant deceleration levels. This surrogate target methodology is illustrated below in Figure 1 at the General Motors Milford Proving Ground test site.

Figure 1 - CAMP Surrogate Target Methodology

In developing a crash alert approach for an FCW system, two fundamental driver behavior parameters have to be considered:

- How hard the driver will brake in response to the alert (i.e., driver deceleration behavior)

- The time it takes for the driver to respond to the crash alert and begin braking (i.e., driver brake reaction time).

These parameters serve as input into vehicle kinematics equations to establish the appropriate warning range as shown in Figure 2. Given values for these parameters, and assuming current speed and lead vehicle deceleration values, an alert range can be derived such that the front bumper of the driver's vehicle would just contact the rear bumper of the lead vehicle during the approach. How hard drivers actually braked in a potential rear-end crash situation was addressed by the first human factors study, referred to as the "baseline study". Driver reaction time in response to an FCW alert was addressed by three subsequent studies referred to collectively as the "interface studies". These interface studies also provided the opportunity to validate the model of driver braking in response to the alert developed in the earlier baseline study.

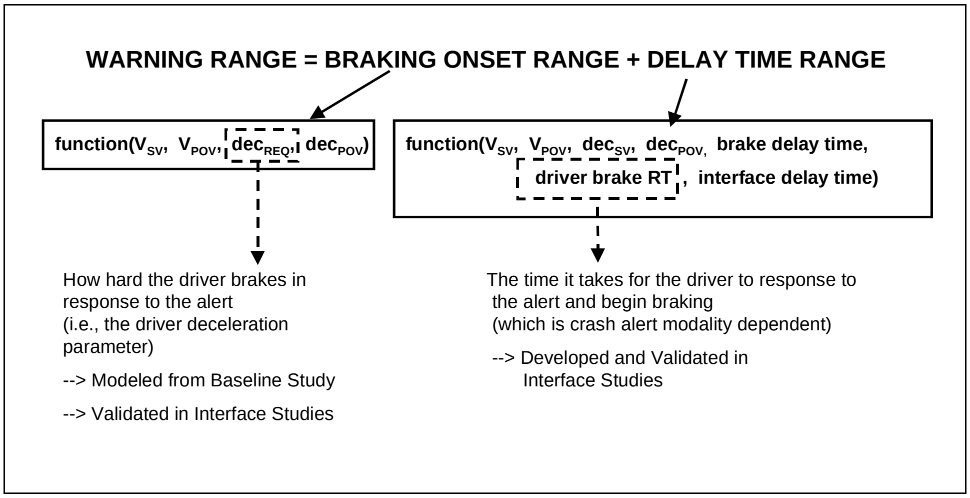


Figure 2 – Driver Behavior Parameter Influence on Warning Range

A fundamental understanding of drivers' "last-second" braking behavior without an FCW system was established in the baseline study. Drivers were asked to wait to brake until the last possible moment in order to avoid colliding with the surrogate target. These last-second braking judgments were made while approaching the surrogate target under a wide range of speed (30 to 60 mph) and lead vehicle deceleration conditions (0 g's to -0.39 g's). In performing these judgments, subjects were instructed to use either "normal", "comfortable hard" or "hard" braking pressure. These different instructions enabled the proper identification and modeling of drivers' perceptions of "aggressive normal braking" and "hard braking". Thirty-six younger, 36 middle-aged and 36 older drivers were tested, with an equal number of males and females in each age group. A wide variety of deceleration-based and time-based (e.g., time-to-collision) driver performance measures were obtained from over 3,800 last-second braking trials.

The driver braking preference data obtained in the baseline study was statistically modeled for use in the subsequent interface studies. This provided an estimate of when and how hard drivers would prefer to brake in response to the alert. Results suggest that drivers' "last-second" braking decisions are deceleration-based rather than time-based as suggested in previous studies. The "actual deceleration" measure, illustrated in Figure 3, is defined as the constant deceleration level required to yield the observed stopping distance. The "required deceleration" measure is 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 slow at the prevailing deceleration value. These deceleration measures varied with driver speed and lead vehicle deceleration rates. That is, drivers braked harder at higher speeds and as the lead vehicle braked harder. This also contrasts with assumptions employed in previous FCW system crash alert timing approaches. Both parameters were relatively uninfluenced by driver age or gender.

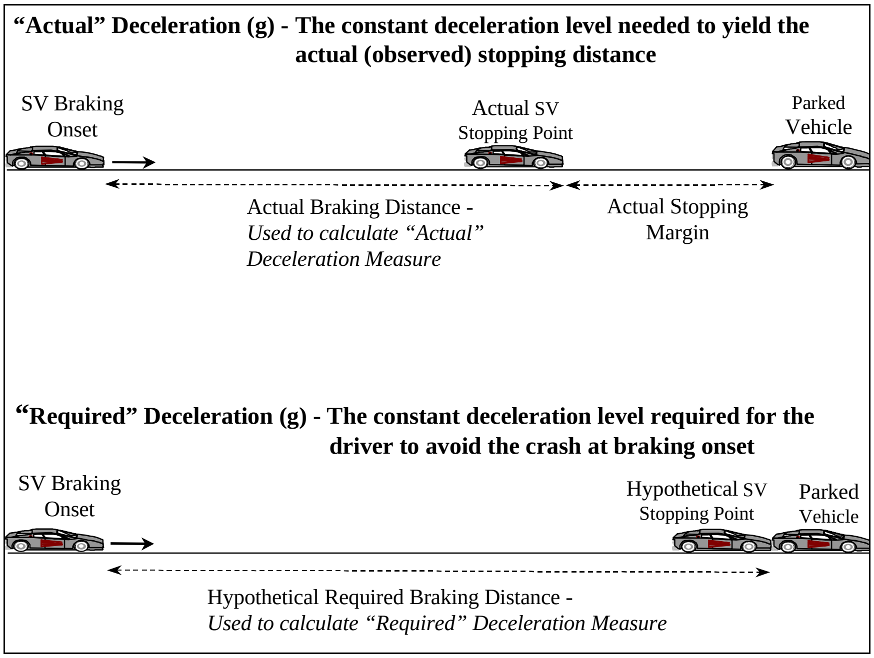


Figure 3 - Definition of Actual and Required Deceleration Measures

The 50th percentile "required deceleration" measure obtained under "hard" braking instructions appears very promising as a proper estimate of how hard the driver would prefer to brake in response to the alert. Figure 4 shows three cumulative probability distributions of assumed driver deceleration parameters for various braking instructions during a typical approach condition. The left most distribution is the "required deceleration" parameter calculated for the "normal" braking instruction. This distribution indicates drivers' preferred braking onset behavior for normal last second braking. Any alert given before the end point of this distribution is reached during an approach might be perceived as "too early" by the remaining percentage of drivers. The middle distribution is the "required deceleration" parameter calculated for the "hard" braking instruction. This data indicates the preferred braking onset behavior for drivers executing a last second hard braking maneuver. An alert issued at some point along this distribution during an approach would be perceived as an acceptable avoidance braking maneuver for those to the left and uncomfortably hard for those to the right. The right most distribution is the "actual deceleration" parameter for the "hard" braking instruction. This curve models the level of (constant) deceleration which drivers actually employed to avoid the crash. As the deceleration level required to avoid the crash increases, this distribution shows the percentage of drivers remaining (to the right) who demonstrated that they were able to brake at this level or harder. Drivers who brake at a level below this point (to the left) in an actual collision situation would still realize some crash mitigation benefit from a reduced impact velocity. Thus by accommodating driver preferences for hard braking it appears possible to minimize "too early" alerts for a high percentage of drivers while still allowing sufficient distance for most drivers to avoid the crash by hard braking. The 50th percentile "required deceleration" parameter for "hard" braking was modeled across all test conditions and used for crash alert timing purposes in the interface studies.

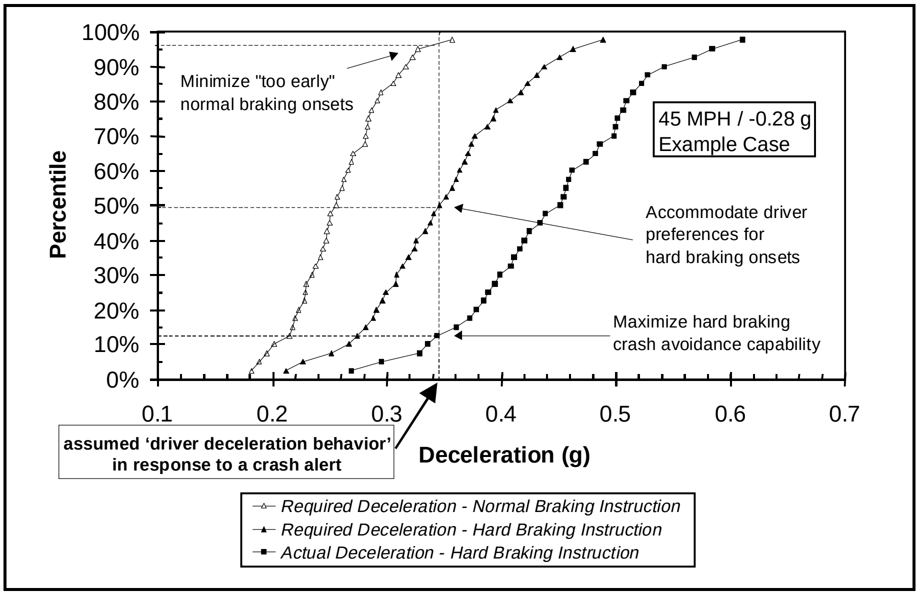


Figure 4 – Required Deceleration Model for Assumed Driver Deceleration Behavior

Three driver interface studies focused on how to present a crash alert to the driver and the assumed driver brake reaction time for crash alert timing purposes. In these interface studies, the driver was simultaneously presented (i.e., in a one-stage manner) crash alerts from two or more sensory modalities. The FCW system crash alert types evaluated are listed 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 + Brake Pulse + Non-Speech Tone
- Flashing High Head-Down Display + Non-Speech Tone

Both visual alerts were located centerline to the driver, with the amber High Head-Down Display (HHDD) located on the top of the dashboard near the cowl of the windshield, and the blue-green Head-Up Display (HUD) positioned slightly above the front hood at a 1.2 m distance. An American National Standards Institute (ANSI) testing procedure was used to select the visual alert format. The auditory alerts included a non-speech tone and a speech message (the word "warning" repeated) played through the front car speakers. These sounds were selected based on drivers' subjective ratings of various alternative sounds on crash alert properties. The haptic alert evaluated was a brief brake pulse or "vehicle jerk" alert.

Younger, middle-aged and older drivers were asked to brake in response to these crash alert types while approaching the surrogate target under the same speed and lead vehicle deceleration conditions examined in the baseline study. Both alerted and unexpected (or surprise) braking event conditions were investigated with naive drivers and drivers experienced with the alerts. In two of the three studies, drivers were unaware the vehicle was equipped with an FCW system crash alert prior to the surprise braking event. Several strategies were employed to create an "inattentive" driver during this surprise event, including engaging the driver in natural conversation, asking the driver to respond to some background-type questions, and asking the driver to search for a (non-existent) indicator light on the conventional instrument panel. During this surprise braking event, the driver was following the lead vehicle at about 30 mph when the lead vehicle suddenly braked at about -0.37 g's without any brake lights. The key driver performance measures used to compare these crash alert types were brake reaction times, the drivers' ability to notice the alerts under surprise conditions, required and actual deceleration levels, and drivers' ratings of the crash alert timing and crash alert types examined.

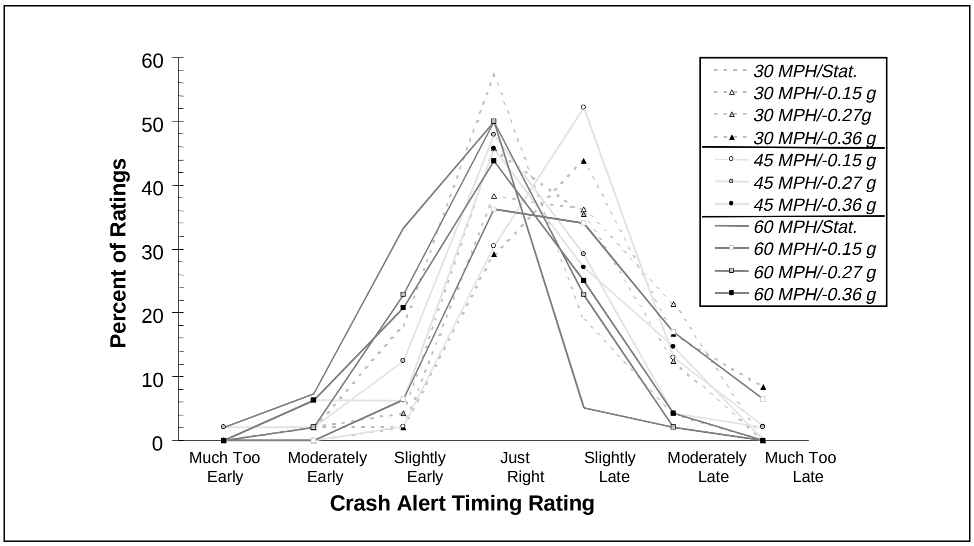


Figure 5 – Driver Subjective Ratings of Alert Timing for Alerted Trials

Results clearly indicated that the timing approach employed was subjectively rated (on average) as "just right" timing under a wide range of speed and lead vehicle deceleration conditions, as shown if Figure 5 for alerted trial conditions. Most importantly, this timing approach allowed 104 of 108 drivers to respond to the crash alert under the surprise braking event conditions in a manner that allowed them to avoid impacts with the surrogate target. Based on data obtained in the interface studies, as well as the previous baseline study, a set of minimum driver interface requirements and a recommended driver interface approach were developed. Recommended values for the assumed driver brake reaction times obtained from interface testing (for crash alert timing purposes) are incorporated in the alert timing requirements discussed in the next section.

Minimum Functional Requirements

The proposed minimum functional requirements for an FCW system were derived by combining the system functionality necessary to address the specific crash problem identified and satisfy the expectations of the driver's mental model developed with the knowledge obtained regarding how drivers normally (prefer to) brake to avoid a rear-end crash. These requirements fall into four categories: driver interface, alert zone, nuisance and environmental.

Driver Interface Requirements

Proposed minimum requirements for an FCW system driver interface and an optional "recommended approach" are summarized in Table 3. As a minimum, a single stage alert consisting of a specific non-speech tone is required. A specific visual icon may be used to supplement this auditory alert if desired. Although optional, use of the visual icon is encouraged to improve alert noticeability for drivers who may not hear the tone, prompt drivers to look ahead in response to an alert, and to explain the non-speech tone to the driver. A single stage crash alert consisting of the non-speech tone combined with a flashing High Head Down Display of the visual icon with the word "WARNING" added is recommended. This combination demonstrated good all-around performance in terms of objective data (e.g., faster driver brake reaction times) and subjective data (e.g., alert noticeability) during interface testing. These findings also support replacing the High Head Down Display with a Head Up Display if desired.

Overall, the speech alerts examined performed poorly in terms of both objective and subjective data. The brake pulse haptic alert is not currently recommended due to a number of unresolved implementation and driver behavior issues (e.g., activation on slippery surfaces, driver braking onset delays, observed foot / body movements).

The single-stage rear-end crash alert recommendation is based on modeling how drivers actually perform this braking task. This supports the notion of a consistent driver "mental model" and simplifies customer education while minimizing nuisance alerts. The proposed crash alert timing requirements based on this model define an acceptable crash alert timing zone for an FCW system as shown in Figure 6. The boundaries for this zone are defined by "too early" and "too late" alert onset range cut-off points. These are oriented toward observed driver hard braking preferences and demonstrated capability, respectively. These cut-off points are calculated from vehicle kinematics equations, for prevailing speeds and lead vehicle deceleration rate, based on assumptions for the two fundamental driver behavior parameters established during testing (driver deceleration behavior and driver brake reaction time). Note that this requirement does not specify the particular crash alert timing approach to be used, but instead simply requires that whatever crash alert timing approach is used yield performance consistent with these boundary timing requirements.

Table 3 - Summary of FCW Driver Interface Requirements

Criteria	Minimum Requirement	Recommended Approach
Number of Crash Alert Stages	**At least one-stage.** (Multi-stage alert allowed if all minimum requirements met at the minimum timing setting <u>and</u> any additional stages do not reduce the effectiveness of the most imminent alert.)	**Single-Stage**
Crash Alert Modality	**Non-Speech Tone** (Sound #8: mixed waveforms with 2500 & 2650 Hz peaks)	**Non-Speech Tone** **+** **Flashing High Head-Down Display** (Steady or flashing Head-Up Display may be substituted for the High Head-Down display if desired)
Crash Alert Display Format (*if provided*)	**Red-Orange, Amber or Yellow indicator** 	**Red-Orange, Amber or Yellow indicator**  WARNING
Crash Alert Timing	**Driver Behavior Parameters (input assumptions for vehicle kinematics equations)** <u>Assumptions for "too early" alert onset cut-off</u>*:* ▪ Deceleration level at braking onset in g's (*) = -0.165 + 0.685*(lead vehicle deceleration in g's) + 0.080* (only if lead vehicle moving) - 0.00877*(speed difference in meters / second) ▪ Brake Reaction Time to crash alert in seconds = 1.52 <u>Assumptions for "too late" alert onset cut-off:</u> ▪ Deceleration level at braking onset in g's = -0.260 - 0.00723*(driver speed in meters / second) ▪ Brake Reaction Time to crash alert in seconds = 1.18	**Driver Behavior Parameters (input assumptions for vehicle kinematics equations)** <u>Assumptions:</u> ▪ Deceleration level at braking onset in g's (*) = -0.165 + 0.685* (lead vehicle deceleration in g's) + 0.080* (only if lead vehicle is moving) - 0.00877*(speed difference in meters / second) ▪ Brake Reaction Time to crash alert in sec. = 1.18

<u>Note</u>: * The domain of validity of this equation is described in the report.

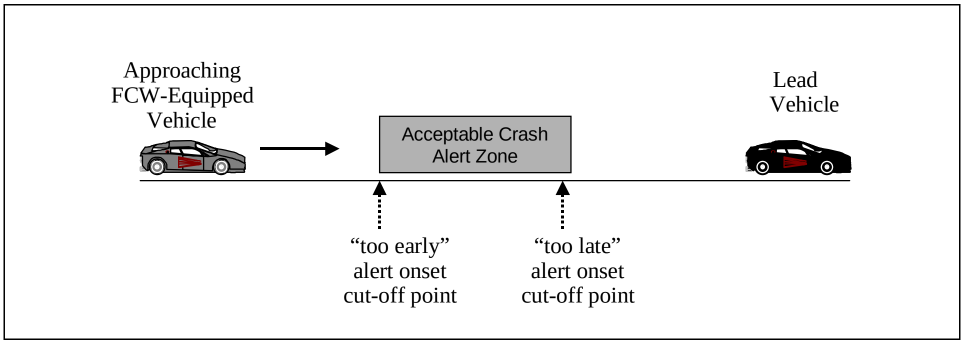


Figure 6 - Illustration of the Acceptable Crash Alert Timing Zone

For the "too early" alert onset range cut-off, the assumed driver deceleration in response to the crash alert is based on a braking onset model developed from the baseline study (no alert). This model is a function of closing speed, lead vehicle deceleration rate, and whether the lead vehicle is moving or stopped. The assumed driver brake reaction time to the crash alert of 1.52 seconds is based on the 95th percentile driver brake reaction time from a surprise braking event study. This data was gathered with naive drivers who were unaware that the vehicle was equipped with an FCW system. These drivers were also distracted at the time of the alert via a request to search the 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 an equation developed from the baseline study (no alert) under the condition when the lead vehicle braked the hardest (-0.39 g's). This equation estimates the 85th percentile actual deceleration value for the "hard" braking instruction as a function of speed. At speeds of 30, 45, and 60 mph, the actual deceleration value estimates are -0.36, -0.41 and -0.46 g's, respectively. Note that these observed driver deceleration values are significantly lower than the maximum vehicle deceleration capability on dry roads, an assumption frequently used in previous alert timing approaches. The assumed driver brake reaction time to the crash alert of 1.18 seconds is based on the 85th percentile driver brake reaction time from a surprise braking event study.

The recommended crash alert timing approach combines the braking onset model developed from the baseline study with the observed 85th percentile driver brake reaction time of 1.18 seconds, also from a surprise braking event study.

Alert Zone Requirements

The FCW system "Alert Zone" defines the region relative to the equipped vehicle within which other vehicles should be evaluated as potential crash threats. This region is defined in terms of the roadway scene consistent with the driver mental model discussed earlier. This is different from the FCW system "Coverage Zone" necessary to provide proper system functionality. No specific requirements are placed on the "Coverage Zone". Figure 7 depicts one possible relationship between these two regions.

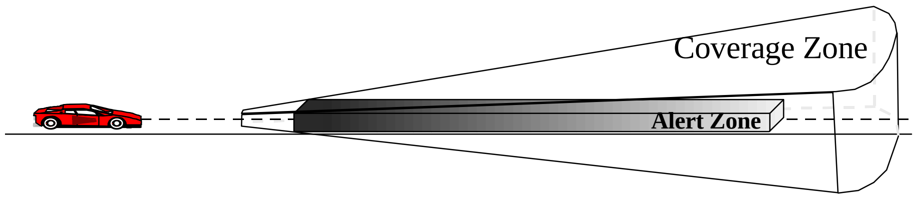


Figure 7 - Coverage and Alert Zone of an FCW System

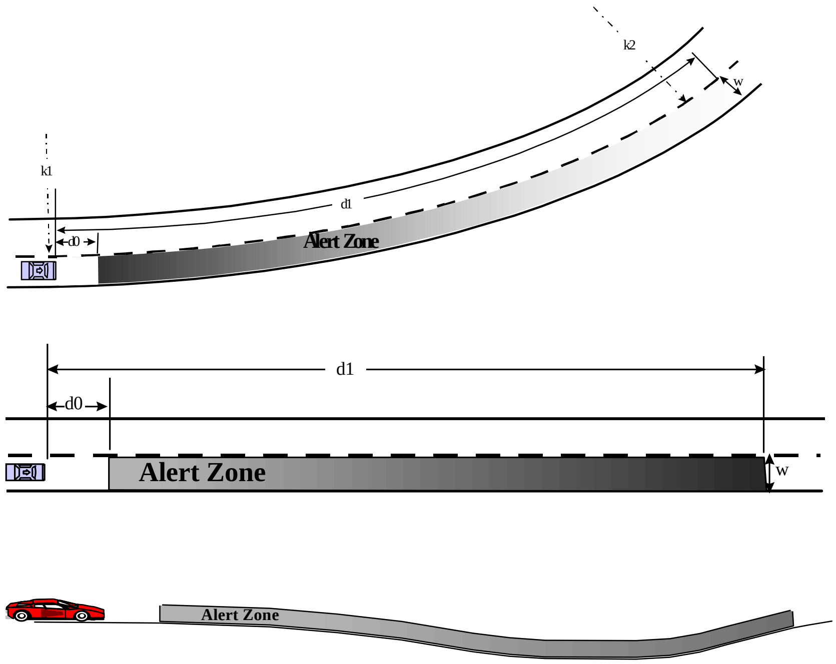


Figure 8 - Alert Zone Horizontal and Vertical Shape and Size

The Alert Zone covers the anticipated path of the FCW equipped vehicle. This zone moves smoothly with the vehicle as it changes lanes. Alerts are required if another vehicle is present in the Alert Zone and its relationship to the FCW equipped vehicle meets the crash alert timing criteria. As shown in Figure 8 the horizontal dimensions of the Alert Zone follows the vehicle's travel lane while the vertical dimensions follow the visible line-of-sight of the road surface. The roadway can be curved and/or banked according to standard AASHTO roadway construction practices. The center of the Alert Zone is centered on the front of the vehicle. The minimum zone width is the width of the vehicle, and the maximum zone width is one standard U.S. lane width, 3.6 meters. Another 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 begins between 0 and 2 meters from the front of host vehicle (d_0)and extends to at least 100 meters (d_1). The 100 meter minimum longitudinal extent is based upon current technology constraints and computer simulations suggesting diminishing benefits for extending detection capability beyond this range. The vertical dimension of the Alert Zone is no less than the height of the vehicle.

This Alert Zone concept is combined with the Crash Alert Timing criteria developed to define the minimum functional requirements for an FCW system from a roadway environment perspective. This is illustrated in Figure 9 for a straight road situation. This approach is used to define a set of objective test procedures that comprehend the crash and operational scenarios identified.

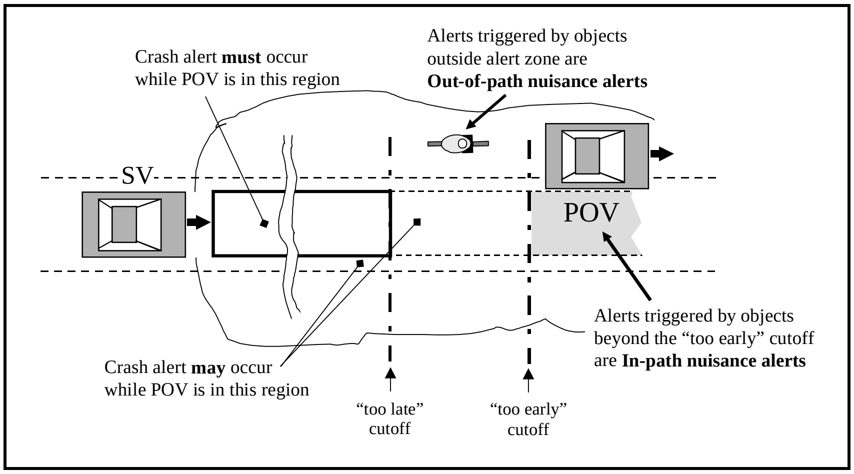


Figure 9 – Combining Alert Zone and Crash Alert Onset Timing Requirements

Nuisance Alert Requirements

The suggested maximum acceptable nuisance alert rates are no more than one out-of-path alert per week and no more than one in-path alert per week for a representative sample of driving conditions (i.e., approximately once per 200 miles of driving over a wide distribution of road types). Examples of these conditions are illustrated in Figure 9. Further work is required to better define "typical" driving and understand driver acceptance of nuisance alerts in various situations.

Environmental Requirements

The FCW system shall function in all weather and ambient lighting conditions, or warn the driver if system operation is limited. This includes day, night, sunrise and sunset conditions. If atmospheric conditions such as rain, snow or fog prevent the FCW system from responding properly to objects at its nominal maximum range, the FCW system should communicate this information to the driver. 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.

Objective Test Procedures

Twenty six dynamic, vehicle-level tests are proposed to evaluate FCW system performance with respect to the proposed minimum functional requirements. These tests are designed to evaluate system performance across a variety of conditions, while still being practical to execute. Total test time is estimated at two to four weeks, not including initial fabrication (special targets / clutter objects), set-up and surveying of test sites. Intended users of these tests are vehicle manufacturers, countermeasure system suppliers and government organizations. Three facilities were considered when designing the tests: the Ford Michigan Proving Ground, the GM Milford Proving Ground and the Transportation Research Center (TRC) in Ohio. The tests are designed to be technology-independent and, hence, applicable to systems that use millimeter wave radar, laser radar and/or computer vision. Each test is described by detailed test procedures and requirements for data reporting and analysis, as well as test documentation. The proposed tests evaluate alert timing but do not evaluate the alert presentation (e.g. audible alert intensity). Tests for the alert modality approach are left to existing industry practices. The complete test regime consists of 17 crash alert tests, which incorporate in-path "operational" issues, and 9 out-of-path nuisance alert tests. A countermeasure must pass each of the 17 individual crash alert tests and score acceptably on the set of 9 out-of-path nuisance alert tests in order to satisfy the proposed FCW system minimum functional requirements.

The 17 crash alert tests (C1 – C17, Table 4) involve dynamic maneuvers of a countermeasure-equipped Subject Vehicle and up to three Principal Other Vehicles. These tests simulate situations in which an alert is required. Data is collected and analyzed to determine whether the alert onset timing meets the requirements described earlier (i.e., the alert cannot be “too early” or “too late”). The countermeasure fails if it provides alerts that are too late on any of the 17 crash alert tests. Alerts that are too early are tallied and later compared against a weighted threshold to determine whether the in-path nuisance alert performance is acceptable. The crash alert tests include a wide variety of vehicle speeds, lead vehicle decelerations, roadway geometries, lighting and visibility conditions and other environmental variables. POVs include mid-sized sedans, motorcycles and large trucks. SV lane change maneuvers and a cut-in maneuver by a slower POV are included.

Nine out-of-path nuisance alert tests are defined (N1 - N9, Table 5). These tests derive from the operational scenarios and involve simulating common driving conditions in which an alert should not occur. These tests combine a variety of vehicle speeds, roadway geometries, POVs and out-of-path objects. The out-of-path objects include guardrails, vehicles in adjacent lanes, an overhead sign, roadside signs and roadway debris. Alerts that occur during these tests are considered out-of-path nuisance alerts. If the weighted sum of the alerts that occur exceeds a specified threshold, the system fails the out-of-path nuisance portion of testing. Scenario weights and a maximum threshold are proposed, based on the preliminary minimum functional requirements described earlier, which limit the acceptable frequency of out-of-path nuisance alerts. The proposed scenario weights are based on an empirical study of objects encountered on a short test route over local public roads. The exact values of the scenario weights and maximum threshold require further refinement through field operational testing and real world deployment experience.

Table 4 - Proposed Vehicle-level Tests

Crash Alert Tests	
C-1	100 kph to POV stopped in travel lane (night)
C-2	80 kph to POV at 16 kph (uneven surface)
C-3	100 kph to POV braking moderately hard from 100 kph
C-4	100 kph to POV stopped under overhead sign
C-5	100 kph to slowed or stopped motorcycle
C-6	SV to POV stopped in transition to curve (wet pavement)
C-7	SV to POV stopped in a curve without lane markings
C-8	SV to slower POV in tight curve
C-9	POV at 67 kph cuts in front of 100 kph SV
C-10	SV at 72 kph changes lanes and encounters parked POV
C-11	100 kph to stopped POV, with fog.
C-12	POV brakes while SV tailgates at 100 kph.
C-13	100 kph to 32 kph motorcycle traveling between two trucks also at 32 kph
C-14	100 kph to 32 kph motorcycle traveling behind a truck
C-15	100 kph to 32 kph Truck
C-16	SV to POV stopped in transition to curve (poor lane markings)
C-17	24 kph SV to stopped POV

Table 5 - Proposed Vehicle-level Tests

Out-Of-Path Nuisance Alert Tests	
N-1	Overhead sign at crest of hill
N-2	Road surface objects on flat roads
N-3	Grating at bottom of hill
N-4	Guard-rails and concrete barriers along curve entrance
N-5	Roadside objects along straight and curved roads (dry & wet pavement)
N-6	U-turn with sign directly ahead
N-7	Slow cars in adjacent lane, in transition to curve
N-8	120 kph between two 60 kph trucks in both adjacent lanes
N-9	N-5, except with poor lane markings

If the countermeasure allows the driver to adjust alert timing, then both crash alert tests and out-of-path nuisance alert tests are executed at the setting that provides the latest alerts. This ensures that the system is capable of providing the required alert timing without exceeding the nuisance alert threshold.

If a countermeasure fails either the crash alert test set or the out-of-path nuisance alert test set, there is a high probability that the system does not meet all the minimum functional requirements for an FCW system. If a countermeasure passes these tests, there is a high confidence that the system would meet the requirements over a wide set of conditions. Nevertheless, field operational testing will be required to learn about drivers' acceptance of the system and its potential effectiveness in the real world.

To validate the objective test procedures, five of the tests were executed (C-3, C-6, C-9, C-13 and N-7). These five tests were selected based on their relative ability to assess the following critical issues: safety of executing the test maneuvers, repeatability of driving the maneuvers within tolerance, and sensitivity of results to test site. Testing was performed using FCW systems available commercially from automotive electronics suppliers. Both millimeter wave and an infrared (laser) based systems were used in each of the tests executed. Tests were executed at the General Motors Proving Ground in Milford, Michigan and at the Transportation Research Center in East Liberty, Ohio. Three test vehicles were instrumented to measure and record ground truth measurements (using differential GPS) and countermeasure data. Data from over 100 test trials was collected and analyzed to evaluate test validation issues. This process led to test procedure changes that simplify execution and more precisely define road curvature and speed requirements. Minor changes in lane markings may be needed to better emulate public road markings in specific curved track sections. Also, if these tests are to be executed routinely, there is value in developing simple aids to assist test drivers in maintaining lane position or holding constant low speeds.

In addition, two FCW equipped vehicles (one millimeter wave radar and one laser radar) were driven over a two hundred mile route around southeastern lower Michigan to identify any significant nuisance alert situations missing from the test procedures. The route was selected to attain the distribution of road types and time of day outlined in Table 6. This distribution of "typical" driving was taken from previous work done by the National Highway traffic Safety Administration (Stewart, Gerald and Burgett, August, "Consideration of Potential Safety Effects for a New Vehicle Based Roadway Illumination Specification, Twelfth International Conference on Experimental Safety Vehicles, 1989). Two new items were added based on this testing.

Table 6 – Public Road Study Route Characteristics

	Percentage of Road Type Traveled						
	RI	RA	RL	UI	UA	UL	Total
Daytime Route	7	14	10	13	24	8	76
Nighttime Route	4	5	3	3	6	2	24
Total	11	19	13	16	30	10	

RI – Rural Interstate
RA – Rural Arterial
RL – Rural Local
UI – Urban Interstate
UA – Urban Arterial
UL - Urban Local

The 21 tests that were not executed are still proposed, based on the validation work done both on and away from the test track. Proving ground testing verified that test execution is safe. Use of Differential Global Positioning System data combined with Inertial Navigation System corrections appears to provide adequate measurement accuracy, and drivers are able to achieve the specified path tolerances with simple aids. The overall test regime appears to meet cost and time constraints. The procedures are comprehensive and understandable to the proving ground staff. The test sites necessary to execute the procedures exist at all three selected facilities. Overall, the validation process suggested that the objective test methodology is a sound and feasible approach to evaluating FCW system performance with respect to the proposed minimum functional requirements.

CHAPTER 1

INTRODUCTION AND BACKGROUND

TABLE OF CONTENTS

List of Figures

1 INTRODUCTION AND BACKGROUND

1.1 Program Description

1.1.1 Goals and Objectives

In 1996, over 1.8 million rear-end crashes occurred in the United States with approximately 2,000 associated fatalities and 800,000 injuries. Rear-end crashes accounted for approximately 25% of all police-reported crashes and 5% of all traffic fatalities. Forward Collision Warning (FCW) systems are now emerging that provide alerts intended to assist drivers in avoiding or mitigating rear-end crashes. This project was conducted to define and develop key pre-competitive enabling elements of FCW systems designed for light vehicles (passenger cars, light trucks and vans). These elements include definition of the specific crash type(s) that an FCW system should be designed to address, the resulting minimum functional requirements for such a system, and objective test procedures for evaluating the extent to which a particular system design provides the desired functionality. Establishing these key elements will enhance consistent countermeasure system implementation across manufacturers. This will result in improved customer understanding and acceptance and help to accelerate the implementation of FCW systems

1.1.2 FCW Project

There are three levels at which the issue of performance requirements and test procedures for a crash countermeasure system can be addressed. The first level determines whether or not the system components are performing according to hardware design specifications. This *countermeasure sub-system* level deals with how to build the system and is not a pre-competitive topic. The second level is the *vehicle-system* level. This level addresses what the desired function should be and a methodology to evaluate the system's ability to perform the function. This second level of function definition and vehicle system evaluation was the focus of this program. This project addressed countermeasures that are vehicle-borne and autonomous. The countermeasures considered were limited to Forward Collision Warning (FCW) systems. This project developed vehicle-system level function specifications (including driver-interface requirements), associated test procedures and performance metrics for FCW systems. The following description details the activities that were undertaken for FCW systems. The major deliverables from this program were a preliminary set of function requirements and objective test procedures for FCW systems. These will make it possible to validate, at the vehicle system level, a particular system's ability to sense required objects and generate appropriate alerts. The third level involves evaluation of the combined *driver-vehicle-system* operating in the traffic . This level of investigation presumes we have already established that the countermeasure-vehicle system is functioning properly. The outcome will depend on how drivers respond to the information presented by the vehicle-countermeasure system. This level of testing is beyond the scope of this program and is left for future fleet studies.

1.2 Project Tasks

Figure 1-1 shows an overview of the project's work tasks and timing. As can be seen, the program was divided into seven overlapping technical tasks. The eighth task was for program management.

ID	Task Name	Start	Finish
1	Task 1 - Conduct Background Information Search and Analysis	2/1/96	8/30/96
5			
6	Task 2 - Identify Key Parameters of Rear-End Crash Type	3/6/96	8/30/96
9			
10	Task 3 - Define Countermeasure Functions	9/2/96	12/16/97
17			
18	Task 4 - Define and Test Interface and Functions	9/2/96	3/31/99
32			
33	Task 5 - Develop Vehicle Level Countermeasure Test Methodology	8/1/96	9/30/98
45			
46	Task 6 - Conduct Tests to Evaluate Test Methodology	4/1/98	1/7/99
50			
51	Task 7 - Recommend Metrics/Procedures/Functions	12/1/98	3/31/99
56			
57	Task 8 - Program Management	2/1/96	3/31/99

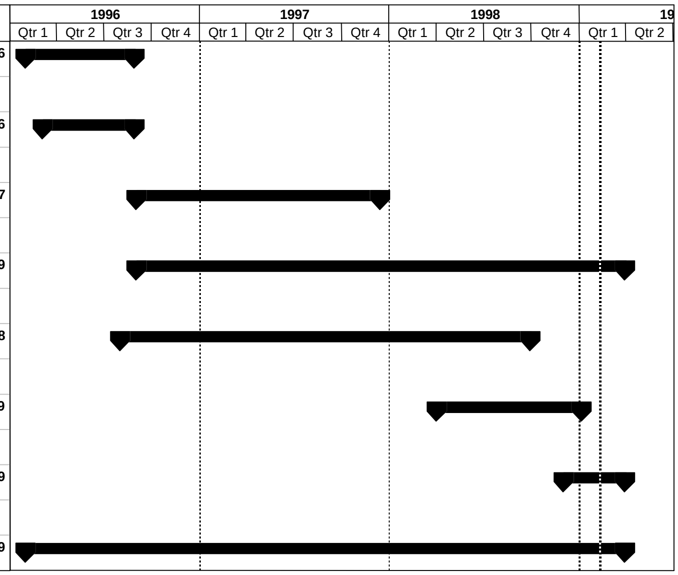


Figure 1-1 Project Tasks GANTT Chart

1.2.1 Task 1: Conduct Background Information Search and Analysis

A significant amount of prior research has been conducted in the areas of crash data analysis, scenario generation, countermeasure function definition, modeling, performance specification, and effectiveness estimation. To ensure a sound basis for the program, the first step was to collect and review the major relevant work, both internal to CAMP and from external sources.

The primary purpose of this task was to lay a solid foundation for the remainder of the project. A bibliography and detailed final work plan was developed under this task. The work plan outlined specific activities required to define the countermeasure functions and objective test procedures for FCW systems. The work plan also included projected resource allocations, a detailed description of task activities, including sub-task milestones, the content of all deliverables, overall program timing and expected level of NHTSA involvement.

1.2.2 Task 2: Identify Key Parameters of Rear-End Crash Type

It is not feasible to address all possible crash scenarios for a given crash type. It was necessary to define and focus on a limited set. This task developed a prioritized list of relevant crash scenarios for which FCW systems may be beneficial. This set of scenarios encompasses those particular scenarios that cause the greatest harm in terms of frequency and overall severity.

These relevant scenarios were identified from existing analyses. Prioritization was based on the frequency and severity of the crash scenarios. Selection of the relevant crash scenarios was made independent of considerations surrounding specific sensing technologies. In addition to the crash scenarios, this task defined key non-crash scenarios (operational scenarios) in which the desired response was established in order to improve driver acceptance of these systems. The addition of operational scenarios to the considerations for functional requirements is a key contribution of this project. The operational scenarios were used to modify the functional requirements contributed by the relevant crash scenarios and resulted in additional requirements to the overall minimum functional requirements. It is widely believed that a high incidence of nuisance alerts will erode driver confidence in an FCW system and could 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.

From the relevant crash scenarios and operational scenarios, key performance parameters were identified. Such parameters include pre-crash factors that contribute to the incident (both during normal driving and immediately prior to the crash), the kinematics of the actual crash, target classifications, environmental factors such as lighting and weather, road geometry and roadside furniture and appurtenances.

Chapter 2 of this report contains a description of the general assumptions, scenario analysis and operational parameters that were developed under Task 2.

1.2.3 Task 3: Define Countermeasure Functions

Based on the problem definition developed in Task 2 and knowledge of the current and projected state-of-the-art, a specification was developed for the functions that FCW systems should perform. In addition to performance during crash-relevant scenarios, the desired performance during other non-crash operational scenarios was specified as well. This specification document was revised and refined after definition and testing of driver interface and countermeasure functions (Task 4 in Section 1.4.4) and conducting tests to evaluate the countermeasure test methodology (Task 6 in Section 1.4.6). Additionally, the list of key crash scenarios was updated based on the increased understanding of the scenarios and applicable FCW countermeasure technologies obtained during this task.

The relevant crash scenarios were subjected to systematic analysis, including modeling and simulation to define the functions and key operational parameters that must be addressed in the performance specifications. The REAMACS (Rear-End Accident Model and Countermeasure Simulation) model developed at Ford was enhanced and used to address rear-end collision countermeasures (Farber & Paley, 1993). It provides an analytical framework for evaluating such factors as warning thresholds, system range requirements, reliability of detection, constancy and accuracy in distance and speed-related functions, and the interaction of these factors with assumptions about driver response times.

REAMACS was used to initially help identify and understand the important scenario and countermeasure parameters in rear-end crashes. The parameters that REAMACS can address include traffic characteristics (following distances and vehicle speeds), braking levels, driver response times and countermeasure algorithms. One use of REAMACS was to conduct sensitivity analyses to determine (1) which crash or pre-crash parameters and assumptions are most important in determining whether or not a crash takes place and (2) what countermeasure characteristics and assumptions are most important in reducing crashes while minimizing nuisance alarms.

The deliverables from this task included a specification of proposed functions and preliminary driver interface requirements for FCW, and results and conclusions from the simulation work performed. A revised and updated version of this specification is included as Chapter 4 in this Final Report. The results of the REAMACS simulations are included in Appendix A.

1.2.4 Task 4: Define and Test Interface and Functions

The objectives of this task were to (1) validate and refine the FCW function specifications developed in the previous task and (2) determine the effects of the FCW system and associated interfaces on driver behavior.

The aim of this human factors portion of the CAMP project was to define driver-interface requirements. More specifically, this effort was focused on defining *when* to present crash alerts (i.e., the crash alert timing) and *how* to present crash alerts to drivers (i.e., the crash alert modality). The critical need for obtaining these data is dictated by the complete absence of data under controlled, realistic conditions involving drivers braking to a realistic crash threat while experiencing production-oriented crash alerts.

In developing a crash alert timing approach for a Forward Collision Warning (or FCW) system, two fundamental parameters involving driver behavior need to be assumed. These parameters serve as input into straightforward vehicle kinematic equations that determine the alert range necessary to avoid a crash.

The first parameter is the time it takes for the driver to respond to the crash alert and begin braking (which includes *driver brake reaction time*). The second parameter is the driver deceleration (or braking) behavior in response to this alert across a wide variety of initial vehicle-vehicle kinematic conditions. Defining this second parameter of driver behavior was the focus of CAMP Study 1. In this study, a strategy was employed to initially develop a fundamental understanding of the timing and nature of the “last-second” braking behavior of drivers *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 of this experimental strategy is that properly characterizing (i.e., modeling) the kinematic conditions surrounding these 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.

The second fundamental crash alert timing parameter involving driver behavior that needs to be considered in developing a crash alert timing approach is driver brake reaction time (or driver brake RT). This second parameter was addressed in three subsequent driver interface studies (all conducted at the GM Milford Proving Ground) in the presence of various FCW system crash alert types under unexpected (or surprise) braking event and expected braking event conditions. These studies focused on how to present a crash alert to the driver (i.e., visual, auditory, and/or haptic/kinesthetic alerts), and provided an opportunity to evaluate and validate the crash alert timing approach assumptions developed from CAMP Study 1.

Appropriate human use guidelines were followed to ensure that the subjects would not be endangered in any way during testing in any of the four studies. CAMP utilized the General Motors' established human use review board that is in compliance with 49 CFR Part 11 (Federal Policy for the Protection of Human Subjects) and NHTSA Order 700-1 (Protection of the Rights and Welfare of Human Subjects in NHTSA-Sponsored Experiments). The experimental protocol for each of the studies was subject to review and approval by a Human Subjects Review Committee at General Motors and at the NHTSA prior to initiation of subject testing. Before participating in any experiment, every subject was required to read and sign an informed consent form, as outlined in 49 CFR Part 11. In the closed-course testing, the research vehicles were insured through one of the partner companies. At least one experimenter was present in each vehicle during testing. The experimenter in the Subject Vehicle had a redundant brake and an alert (called a "bail out" crash alert) indicating when to override the subject by hitting the brake to ensure the participant's safety.

Chapter 4 of this final report contains a detailed description of the studies and results from this task. In addition, the Driver-Vehicle Interface and Timing Requirements sections of Chapter 4 are based upon the results of the Human Factors Studies.

1.2.5 Task 5: Develop Vehicle-System Level Countermeasure Test Methodology

The relevant crash scenarios developed in Task 2 and the system functional requirements developed in Task 3 were used to define dynamic test scenarios. These test scenarios are, in effect, the procedures for performance testing of vehicle-system level crash countermeasures. Two types of test scenarios are included. First, tests for the *crash-relevant scenarios* were defined. This is the set of scenarios that the system is designed to address. These tests determine if alerts occur too late as well as "too early" (i.e., when they would be considered nuisance alerts).

Second, tests for other common non-crash *operational scenarios* were identified and specified to represent operating conditions under which activation of the countermeasure might or might not be appropriate. These are the conditions that might produce false alarms, sometimes referred to as nuisance alarms. Both types of scenarios were defined at a level of detail sufficient to specify full-scale vehicle test procedures. Consistent system response in both sets of scenarios is important in order to reduce rear-end crash frequency in the real world. The system must be capable of providing effective warnings to prevent or mitigate the crash in crash-relevant scenarios without causing excessive nuisance alarms in other (non-crash) operational situations.

A parallel sub-task procured test vehicles, equipment, and FCW systems for use in evaluating the test procedures under Task 6. IR and radar were acquired from leading FCW suppliers. NHTSA was substantially involved in the process leading to the selection of the FCW systems used by CAMP. An instrumentation sub-task defined, procured, and installed vehicle equipment for collecting ground truth during testing.

To support the tests, and to provide consistent test results, there should be consistency in the props and vehicles used in testing, such as representative valid targets, non-target objects, roadside furniture, appurtenances, road geometry, and operational procedures, as well as the instrumentation and data logging required to measure and record the critical parameters of the crash as identified previously. Chapter 5 includes CAMP’s definitions, requirements, and recommendations for these items.

A data analysis and reporting plan was developed to evaluate the data collected in the testing. It provides procedures for analysis and documentation of the data collected using the test procedures. This process identified candidate performance metrics for FCW systems.

This task also developed a test plan for evaluating the objective test procedures for FCW systems. This plan addressed full-scale vehicle testing for the minimum performance requirements. The plan and the results of its execution are documented in Chapter 7.

The parts of this Final Report that were developed under Task 5 include:

- The proposed test methodology included in Chapter 5.
- Data analysis and reporting requirements described in Chapter 5.
- The instrumentation described in Chapter 5.
- The plan for the test procedure evaluation reported in Chapter 5.

1.2.6 Task 6: Conduct Tests to Evaluate Test Methodology

Vehicle-system level testing was conducted using third party hardware obtained in Task 5 from countermeasure suppliers. The testing was performed using professional drivers on a closed course to confirm the procedures, measurement techniques, and data analysis plan. The test methodology was evaluated using two sensor technologies, radar and IR sensing.

The goal of this task was to evaluate the proposed test procedures. Chapter 6 of this report describes the evaluation of the objective test procedures. In addition, any modifications to the objective test procedures suggested by the evaluation have been incorporated into the appropriate chapters of this report.

1.2.7 Task 7: Recommend Metrics / Procedures / Functions

This task allowed time for revision and iteration of the sections developed in each task based on information discovered and issues raised during the project. The final report for the project was written to update the preliminary reports developed in previous tasks.

This project was intended to establish the functional requirements and objective test procedures for rear-end crash countermeasures. A substantial portion of Task 7 was for final reviews of the Final Report with Product Development, Safety, and Research personnel at Ford and General Motors. This task allowed time for iteration of the final report, based on the comments received from the reviews, prior to publication.

1.2.8 Task 8: Program Management

- This project was jointly managed by two project managers who are employees of Ford and General Motors. Their responsibilities were:
- To oversee the tasks so that milestones and deliverables are timely and of high quality.
- To revise the project plan, as necessary, in cooperation with the NHTSA.
- To prepare reports and material for information exchange meetings, as agreed in the project plan, in the required format.
- To coordinate with other NHTSA contractors engaged in related activities.
- To interface with Ford and General Motors, to ensure prior and current relevant activities were utilized in this project to the extent possible, and to facilitate acceptance of CAMP results by Ford and General Motors.

The deliverables under this task were:

- Annual research reports
- This final project report and briefing
- Quarterly briefings

1.3 Report Organization

The remainder of this report is organized according to the tasks just described. Chapter 2 covers fundamental assumptions about FCW systems used throughout the project. It then provides a review of previous work and derives the crash scenarios and operational scenarios used in subsequent tasks. Chapter 3 describes the human factors studies that were performed under Task 4. It includes the conclusions that were derived from these studies regarding crash alert timing and the methods for presenting this crash alert to the driver. Chapter 4 includes the minimal functional requirements and guidelines that were derived from human factors studies and the scenario descriptions. Chapter 5 describes the test procedures that were derived from the minimal functional requirements. These include the required track configurations, props, and detailed descriptions of the driving maneuvers that must be performed to simulate each scenario. Chapter 6 includes requirements for instrumentation and documentation during testing and the analysis that must be done on the data collected during execution of the tests. Chapter 7 describes the testing that was performed to evaluate the test procedures. Included in this chapter is a description of the FCW systems and instrumented vehicles used for this purpose.

1.4 References

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CHAPTER 2

ROADWAY SCENARIOS FOR FORWARD COLLISION WARNING (FCW) SYSTEMS

TABLE OF CONTENTS

List of Figures

List of Tables

2 ROADWAY SCENARIOS FOR FORWARD COLLISION WARNING (FCW) SYSTEMS

2.1 Fundamental Assumptions and Purpose of FCW Systems

No single crash-avoidance countermeasure can be effective in preventing or mitigating all types of crashes. The variety of crash types that occur, and the numerous causal factors involved, make it necessary to focus individual CA systems on particular categories of collisions defined by certain crash scenarios.

The purpose of an FCW system is to provide warning(s) to drivers as an aid in avoiding or reducing the severity of crashes involving the FCW-equipped vehicle with the rear end of another vehicle.

The CAMP project selected several fundamental assumptions about an FCW system that were used in all subsequent developments.

- The system is autonomous and does not require cooperative features on other vehicles or external infrastructure beyond what currently exists (e.g., the FCW may use lane markings when present but cannot require special transponders placed at lane boundaries).
- The system provides alert(s) only and does not provide active, sustained control of the host vehicle in order to avoid an impending crash.
- The system can only sense objects that are visible by line-of-sight from the front of the driver's vehicle.
- The system continuously monitors the forward coverage zone and evaluates potential threats.

An FCW system is faced with the very difficult task of distinguishing potentially threatening vehicles from other non-threatening vehicles and roadway objects that occur in the complex roadway environment. An FCW system that is required to provide adequate warning for all drivers to avoid all imaginable rear-end crashes would be required to issue so many alerts that it would quickly become a nuisance, preventing driver acceptance of FCW systems and thus limiting the potential benefits. A more feasible goal for FCW systems would be to warn in time to help the driver avoid the most common rear-end crashes by driver braking only (not steering) while issuing few enough nuisance alerts that driver acceptance is possible.

The project participants believe that drivers expect an FCW system to help them avoid rear-end crashes with other vehicles without too many annoyances. Drivers also expect that FCW systems function so they can use a consistent, easily understood mental model of what an FCW system does. An example of a simple *mental model* is that an FCW system acts like an ever-vigilant passenger who observes the road ahead of the vehicle and produces alerts when such a passenger would normally be alarmed.

2.2 Roadway Scenario Overview

The following sections describe a set of automotive crash scenarios (relevant scenarios) for which FCW technology may potentially help drivers prevent or mitigate the associated collision. They further define key non-crash scenarios (operational scenarios) in which the desired response of an FCW system should be established in order to improve driver acceptance of these systems. This work is based on extensive crash data analyses performed by the NHTSA Office of Crash Avoidance Research (OCAR), further detailed analysis performed by the General Motors Crash Avoidance Department and the experiences of the CAMP partners with current FCW system technology. The set of relevant and operational scenarios identified here, collectively known as *roadway scenarios*, were used to establish the minimum functional requirements and objective test procedures for FCW systems contained in Chapters 4 and 5.

The methodology utilized to develop the scenarios began by reviewing previous crash statistics in the United States. The crash statistics reports are summarized in Section 2.3. The analysis assumed the model of an automotive FCW system described in the previous section. Previously defined crash scenarios were then reviewed in order to ascertain which scenarios should establish performance requirements for future FCW systems. The selection of the scenarios is complicated in that it depends upon the frequency and severity of each crash type, not only available FCW sensing and data processing technology. These relevant scenarios, together with common operational scenarios that should not elicit a response from an FCW system, formed the basis for establishing FCW minimum performance requirements. Crash scenarios that do not drive minimum performance requirements may still benefit from FCW technology; however, solving these crash problems will not be the primary focus of FCW systems.

Figure 2-1 shows how the relevant scenarios developed in this task were used to derive functional requirements for FCW systems. These requirements, in turn, lead to the development and validation of the test methodologies for FCW systems described in Chapter 5.

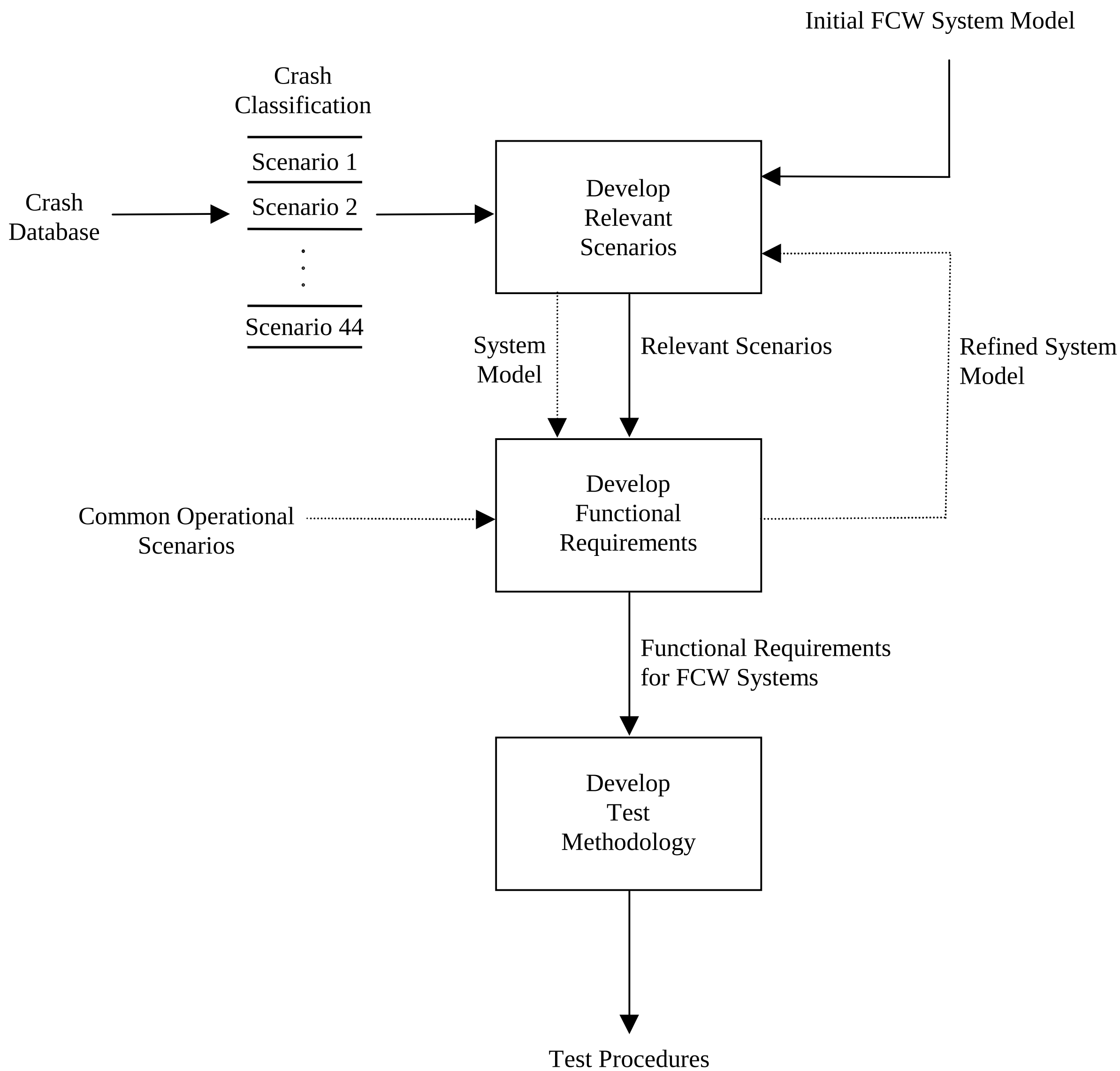

Figure 2-1 Generation and Use of Relevant Scenarios

2.3 Summary of Previous Crash Statistics Research

This section briefly summarizes selected reports on U.S. crash statistics. Frequency, severity and the pre-crash factors for various crash types will be discussed. It should be noted that the crash statistics reported in this section are **not** normalized for exposure. Furthermore, this section is not intended to be an exhaustive literature review, but rather a synopsis of the portion of the crash problem for which FCW technology may be relevant.

2.3.1 Knipling, Wang, and Yin (1993). *Rear-end crashes: Problem size assessment and statistical description.* DOT-HS-807-995.

2.3.1.1 Frequency

Knipling, et al. (1993) used the 1990 GES and FARS databases as the principal sources for their assessment. They reported that in 1990 there were 1.5 million police reported rear-end crashes. Of those, 2,084 fatalities and 844,000 injuries (of which 68,000 were considered serious) occurred. Rear-end (RE) crashes accounted for 23.4% of all crashes and 4.7% of all fatalities in 1990.

2.3.1.2 Conditions

The authors also reported that most rear-end crashes occur on straight, level roads (90%) which are dry (78.8%). Rear-end crashes occur only 18% of the time in rainy conditions and only 1.9% in snowy conditions. For rear-end crashes, only 0.5% occur in fog; view obstruction is rarely cited. Most RE crashes occur between 6 a.m. and 6:30 p.m., which is related to the fact that 76.5% occur in daylight and 14.2% in dark, lit conditions. Only 6% of these crashes occur in dark, non-lit conditions. Friday is the day rear-ends are most frequent and they occur least frequently on Sundays. Additionally, the majority of rear-end collisions occur in rural areas, those with populations less than 25,000. The next highest is urban areas (over 100,000), then areas with populations between 50,000 and 100,000, and finally areas with populations between 25,000 and 50,000. Interestingly, 54.5% of drivers were not given any citation, 23.7% were cited with “other violations,” 13.7% were given a speeding citation, and only 3% were cited as under the influence of alcohol and/or drugs. It should be noted that the number of citations given may not correspond to the actual presence of illegal actions.

2.3.1.3 Lead Vehicle Stationary or Moving

Rear-end crashes can be broken into two distinct groups based upon the lead, or struck, vehicle velocity: Lead Vehicle Stationary (LVS) or Lead Vehicle Moving (LVM). In this study, the stationary or moving description of the lead vehicle refers to the state when struck, and not to the state immediately before the impact. LVS crashes account for 70% of all rear-end crashes and LVM crashes account for 30%. Table 2-1 gives details for each group in terms of frequency and severity, roadway and speed related variables, pre-crash maneuvers and causes.

	LVS	**LVM**
Frequency and Severity		
Police reported crashes [1]	1.05M (69.7%)	0.46M (30.3%)
Fatalities [2]	1,647	1,338
Fatalities per crash	0.0016	0.0029
Killed and Incapacitated	3%	4.6%
Roadway Related		
Non-Junction [3]	35.4%	54.2%
Divided roads	67.1%	57.3%
Fog Related	0.6%	0.2%
Speed Related		
Posted roadway speed over 55 mph	13.4%	28.6%
Median posted roadway speed	39 mph	42 mph
Actual speed reported [4]	22 mph	32 mph
Actual speeds over 55 mph	2.5%	14.8%
Striking Vehicle Pre-Crash Maneuver		
Going straight	88.6%	25.8%
Slowing stopping	6.7%	55.6%
Turning left	na	8.1%
Turning right	na	6.5%
Tri-Level Causes		
Vehicular	11%	17%
Human	93%	92%
Recognition	82%	67%
Decision	24%	50%
Alcohol	9%	not reported
Environment	9%	17%

1 Estimated 1.8 million **non**-police reported rear-end crashes.
2 LVM less frequent, but more severe.
3 54.9% of all rear-ends are intersection related.
4 Crash speed was unknown in 70%.

Table 2-1 LVS and LVM Rear-End Crash Statistics

2.3.2 National Safety Council (1993). *Accident facts.*

The National Safety Council reported that, for 1992, there were 10 million police-reported crashes in the U.S. (see Table 2-2 for a partial listing). It is interesting to note that rear-end crashes account for 24% of the crashes and 5% of the fatalities, indicating a frequent but low severity crash. Pedestrian and head-on collision account for only 2% of the crashes each, but for 15% and 13% of the fatalities, respectively. This indicates that rear-end crashes are less severe, but more frequent.

	Fatal	% of Fatal	Injury	% of Injury	Total	% of Total
Total	*35,800*		*1,400,000*		*10,000,000*	
Pedestrian	5,500	15.36	60,000	4.29	180,000	1.80
Head-on	4,500	12.57	36,000	2.57	220,000	2.20
Rear-end	1,700	4.75	329,000	23.50	2,360,000	23.60
Pedacycle	700	1.96	39,000	2.79	150,000	1.50
Animal	100	0.28	9,000	0.64	240,000	2.40

Table 2-2 National Safety Council Accident Facts for 1992

2.3.3 Campbell, Wolfe, Blower, Waller, Massie, and Ridella (June 1990). *Accident data analysis in support of collision avoidance technologies.* UMTRI-90-31. University of Michigan Transportation Research Institute.

The authors conducted a survey of five crash types in order to estimate the frequency of each collision type. Collision types investigated were Single Vehicle Non-Intersection, Multiple Vehicle Crossing Paths Signalized Intersection, Multiple Vehicle Crossing Paths Signed Intersection, Multiple Vehicle Non-Intersection Driveway/Parking Lot, and Multiple Vehicle Non-Intersection Same Direction. The focus was on common crashes of ordinary drivers. They did not use drivers under the age of 16, intoxicated drivers, or reckless drivers. They also excluded pedestrian and pedacycle collisions. Only ordinary drivers and common collisions were included in this study.

The authors examined 215 police reports from Michigan. The sample was controlled by crash type and age. Additional controls, such as lighting conditions, urban/rural, and presence of signals, were used for some crash types. The data for rear-end collisions are presented below.

2.3.3.1 Same Direction Non-Intersection

Of the 215 sampled crashes, 37 were classified as Same Direction Non-Intersection. Of these 37 crashes, 24 were rear-end collisions. More than one-third of the rear-end collisions involved more than two vehicles. Younger and older drivers were over-represented (they have more crashes of this type). Additionally the authors found that in 30.7% of the crashes the lead vehicle was stopped, in 22.7% the lead vehicle was going straight, in 13.8% the lead vehicle was turning, and in 10% the lead vehicle position was unknown.

2.3.4 Treat, Tumbas, McDonald, Shinar, Hume, Mayer, Stansifer, and Castellan (May 30, 1979). *Tri-level study of the causes of traffic accidents: Executive summary*. DOT-HS-805-099.

This report documented the findings of the "Tri-Level Study of the Causes of Traffic Accidents". Briefly, the term "tri-level" refers to the three levels of data collection:

- Baseline
- On-site investigation (n=2,258)
- In-depth (n=420)

The cause of the crash was broken into three main categories

- Human
- Environment
- Vehicle

Human errors were cited as a definite cause in at least 64% and a probable cause in as many as 93% of the crashes. The most common probable human errors were:

- Improper lookout (23%)
- Excessive speed (13%)
- Inattention (15%)
- Improper evasive action (13%)
- Internal distraction (9%)

Environmental factors were cited as the definite cause in only 12% of the crashes. Environmental factors were cited as probable causes in 34% to 35% of the crashes; view obstruction was the most frequent probable cause (12%), followed by slick road (10%), and design problems (5%). Vehicle problems (e.g., gross brake failure, inadequate tire tread) were cited as definite causes in only 4% and probable causes in 9% to 13% of the crashes.

2.3.5 Institute for Research in Public Safety (February 1975). *An analysis of emergency situations, maneuvers, and driver behaviors in accident avoidance.* Bloomington, IN: Indiana University.

This report examined 372 crashes occurring from 1971 to 1974 in Monroe County, Indiana. The data were collected through the in-depth investigations in the Tri-Level study. Reported in Table 2-3 are data from the collisions of interest. The second column is the percentage of all crashes by collision type. The third column is the percentage of all crashes in which the researchers judged "that at least one driver had time to attempt an additional or different maneuver." This value could be used as a rough estimate of the maximum percentage of crashes an FCW system might potentially help.

Crash Category	% of All Crashes [1]	% of Crashes Avoidable [2]
Rear-end, 2 vehicles	12.9	79.2
Rear-end, >2 vehicles	1.9	71.4

1 Number of crashes in category divided by the total (372)

2 Avoidable is defined as an crash in which at least one driver was judged to have had time to attempt an additional or different maneuver.

Table 2-3 Percentage of Preventable Crashes

2.3.6 Najm, Mironer, and Yap (1996). *Dynamically distinct precrash scenarios of major crash types.* Memo DOT-VNTSC-HS621-PM-96-17. Cambridge, MA: US DOT Volpe National Transportation Systems Center.

This report identified dynamically distinct pre-crash scenarios for five major crash types:

- Intersection crossing path
- Single vehicle road departure
- Rear end
- Lane change
- Backing

Twenty dynamically distinct scenarios were identified for rear-end crashes. The crashes are distinguished by the pre-crash movement and critical pre-crash events. Pre-crash maneuvers include steady speed, slowing, starting, stopped, negotiating a curve, merging, passing and turning. The critical event descriptions included speed differential or encroachment.

The NHTSA General Estimates System (GES) and Crashworthiness Data System (CDS) data bases were used to make two estimates of the percent of each crash type that exhibited each dynamically distinct scenario. The first estimate was the percentage of rear-end crashes in the database that fell into each scenario. The second involved weighting each scenario using the corresponding National Inflation Factor to compensate for the small sample size in the database. The most common rear-end crash scenario was when the striking vehicle is going straight at constant speed while the stricken vehicle was slowing in traffic. This scenario included cases where the stricken vehicle was coded as stopped due to a traffic-control device or to make a turn on a straight road. The next two most common rear-end crash scenarios were when the striking vehicle was going straight at constant speed or negotiating a curve while the stricken vehicle was stopped in the lane of traffic. Combined, these three scenarios were estimated to represent about 80% of all rear-end crashes.

	Striking Vehicle's Maneuver	**Stricken Vehicle's Maneuver**	**Critical Event**	**Relative Frequency of Occurrence (%)**	**Adjusted Relative Frequency of Occurrence (%)**
1	Going straight, constant speed	Slowing in traffic lane	Speed differential	56.3	47.4
2	Negotiating a Curve	Stopped in Traffic Lane	Speed Differential	19.2	14.1
3	Going straight, constant speed	Stopped in traffic lane	Speed differential	5.0	10.4
4	Going straight, constant speed	Going straight, constant speed	Speed differential	1.5	5.9
5	Going straight, constant speed	Slowing in traffic lane	Speed differential	5.3	4.4
6	Going straight, constant speed	Starting in lane	Speed differential	0.6	2.2
7	Changing lanes	Slowing in traffic lane	Speed differential	3.7	2.2
8	Negotiating a curve	Slowing in traffic lane	Encroachment	3.7	2.2
9	Negotiating a curve	Changing lanes	Encroachment	1.0	1.5

Table 2-4 Dynamically-Distinct Rear-End Pre-Crash Scenarios

2.3.7 General Motors (1996). *44 crashes.* Warren, MI: North American Operations, Crash Avoidance Department.

"44 Crashes" is intended to define the distribution of annual U.S. crashes. The 44 crashes were compiled from a number of sources, including police reports, the Tri-Level study, and work done at UMTRI (University of Michigan Transportation Research Institute). Each crash, or scenario, contains a cause, a crash configuration, a representative narrative, and the associated frequency and losses. The reader should refer to the original document for more information concerning the crash data and classification.

Table 2-5 lists the name and a brief description of each crash. In the description, SV is the Subject Vehicle and POVs are the Principal Other Vehicles (or lead vehicles). The letter in the subscript represents the vehicle letter set forth in "44 Crashes"

Table 2-5 lists the crashes by number, cause-crash name, group, percentage of vehicles crashed, direct costs and years of life and functioning lost. The percentages of vehicle crashes were derived from the "crossing of a typology with a causal factor" (p. 8). The direct costs were defined as the actual dollar expenditures related to the damage and injury caused by the crash. Years of functioning and life was defined as "the number of years lost to fatal injury plus the number of years of functional capacity lost to nonfatal injury" (Miller, Lestina, Galbraith, Schlax, Mabery, Deering, Massie and Campbell, 1995, p. 3).

Table 2-5 Description of the 44 Crashes

#	Name	Description
1	Struck human	SV_A strikes a human.
3	Struck animal	SV_A strikes an animal.
9	Drowsy driver	The driver of SV_A falls asleep and departs the roadway.
10	Aggressive departure	The driver of SV_A drives aggressively, perhaps too fast, loses control and departs the roadway.
11	Slick road departure	The driver of SV_A loses control on a slick road and departs the roadway.
12	Rough road departure	The driver of SV_A loses control of the vehicle on a poorly maintained or designed road. SV_A departs the roadway.
13	Avoidance departure	SV_A makes an avoidance maneuver and loses control of the vehicle, departing the roadway.
18	Impaired departure	The driver of SV_A is legally impaired and loses control of the vehicle and departs the roadway.
19	Back into object	SV_A is backing out of a driveway and strikes an object (POV_B).
22	Ran red/"T-bone"	SV_A runs a red light and collides with POV_B.
28	Slick road, ran stop	SV_A approaches an intersection. Due to slick roads SV_A cannot stop at the stop sign. SV_A collides with POV_B.
30	Inattentive, ran stop	SV_A is not paying attention[1], runs a stop sign and collides with POV_B.

#	Name	Description
33	View obstruction	SV_A cannot see POV_B due to some obstruction. SV_A collides with POV_B.
35	Looked but didn't see	SV_A looks for oncoming traffic, but does not see any; thus crashing with POV_B.
37	Sirens	SV_A does not see POV_B (an emergency vehicle) and either strikes or is struck by POV_B.
38	Left turn clip	SV_A is making a left turn. POV_B is waiting at the stop line on the street into which SV_A is turning. SV_A misjudges the turn and strikes the front left corner of POV_B.
40	Wrong driveway	SV_A is exiting a driveway. SV_A incorrectly assumes POV_B is making a specific maneuver and pulls out in front of POV_B, resulting in a collision.
44	Wave to go	SV_A is waiting at a cross street, when POV_B "wave's him/her to go." Not seeing POV_C, SV_A pulls into and collides with POV_C.
47	Turn into passer	SV_A is following POV_B. SV_A decides to pass POV_B. POV_B decides to make a turn. They collide.
48	Back into roadway	SV_A is backing into a roadway and does not see POV_B in oncoming traffic, creating a collision.
52	Tailgate	SV_B is following POV_A too closely. POV_A slows or stops, and SV_B strikes the rear-end of POV_A.
56	Distracted rear end	SV_A, following POV_B, is distracted.[2] POV_B slows or stops and SV_A strikes the rear-end of POV_B.
58	Avoidance, rear end	SV_A makes a maneuver to avoid POV_C. However, the maneuver puts SV_A behind POV_B, who is slowing or stopped. SV_A strikes the rear-end of POV_B.
61	Pedal miss	SV_A intends to brake; however, he/she misses the brake pedal and collides with POV_B.
62	Inattentive rear end	SV_B, following POV_A, is not paying attention. POV_A slows or stops and SV_B strikes the rear-end of POV_A.
64	Stutter stop	SV_B is stopped behind POV_A. Assuming POV_A is going to move forward, SV_B accelerates. POV_A decided not to move; thus, SV_B strikes the rear-end of POV_A.
66	Aggressive rear end	SV_B is driving aggressively, perhaps too fast. POV_A has slowed or stopped. SV_B does not have enough time to stop and strikes the rear-end of POV_A.
68	Maintenance	SV_B is unable to control his/her vehicle due to some mechanical failure; thus, colliding with POV_A.
74	Slick road, rear end	SV_B, following POV_A, tries to slow or stop. Due to slick roads SV_B cannot slow or stop and strikes the rear of POV_A.
75	Passing clip	SV_A is following POV_B and decides to pass. SV_A misjudges the passing maneuver and strikes a rear corner of POV_B.
76	Lane change right	SV_A, intending to move into the right lane, looks but does not see POV_B in that lane. SV_A changes lanes and forces POV_B to the right.
78	Visibility rear end	Visibility is limited. SV_A, following POV_B, cannot see that POV_B has slowed or stopped. SV_A strikes the rear end of POV_B.
79	Lane change left	SV_A, intending to move into the left lane, looks but does not see

#	Name	Description
		POV_B in that lane. SV_A changes lanes and forces POV_B to the left.
80	Lane change rear end	SV_A moves into an adjacent lane. POV_B, who is in the lane SV_A moved into, does not have enough time to slow. POV_B strikes the rear end of SV_A. POV_C, who is following POV_B, also does not have enough time to slow. POV_C strikes the rear end of POV_B.
82	Back track	SV_A backs into POV_B.
83	U-turn	SV_B decides to make a U-turn. POV_A, unaware of the intentions of SV_B, is driving on the left of SV_B. SV_B makes the U-turn in front of POV_A. POV_A collides with SV_B. This scenario also includes a turn across lanes from wrong lane.
91	Inexperience, departure	SV_A, an inexperienced driver, loses control of the vehicle and departs the roadway.
92	Impaired, head-on	SV_A is legally impaired and drives into the on-coming lane. POV_B, in that on-coming lane, collides head-on with SV_A.
93	Slick road, head-on	The roadway is slick. SV_A and POV_B are traveling opposite directions. Due to the road conditions, one or both lose control and collide.
94	Run red into left turner	SV_A is making a left turn. POV_B runs a red light and collides with SV_A.
96	Misjudgment, left turn	SV_A is planning to make a left turn. Assuming he/she has enough time, SV_A executes the maneuver in front of POV_B. POV_B cannot stop and crashes with SV_A.
99	View obstructed left	SV_A is planning to make a left turn. SV_A cannot see the oncoming vehicle, POV_B. SV_A executes the maneuver in front of POV_B. POV_B cannot stop and crashes with SV_A.
100	Miscellaneous	Any crash that does not fit into one of the 43 categories.
101	New	"This crash would not have occurred without the introduction of a new safety technology. The driver selected to use the technology for increased mobility rather than an increase in safety as intended" (p. 52).

1 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). See Section 4.4.1 for additional details.

2 For distracted driver "some event, activity, object or person within his vehicle [or outside the vehicle], compelled, or tended to induce the driver's shifting of attention away from the driving task" (Treat et al., 1977, p. 203). See Section 4.4.2 for additional details.

Table 2-6 Frequency and Costs for the 44 Crashes

Number	Name	% Crashed (14,507,000 cars)	% Direct Cost ($66066 M)	% Years Lost (2,059,000 yr.)
1 [B]	Struck human	1.0	2.8	5.4
3 [C]	Struck animal	4.0	1.8	0.3
9	Drowsy driver	1.0	1.9	3.4
10	Aggressive departure	3.0	6.5	10.9
11	Slick road departure	2.0	3.9	6.6
12	Rough road departure	1.0	1.8	2.9
13	Avoidance departure	3.0	3.9	5.7
18	Impaired departure	2.0	4.0	6.7
19	Back into object	1.5	0.9	0.7
22	Ran red/“T-bone”	4.1	4.9	3.8
28	Slick road, ran stop	2.0	1.8	1.6
30	Inattentive, ran stop	2.5	2.8	2.8
33	View obstruction	1.0	1.0	0.7
35	Looked but didn’t see	10.0	10.2	8.9
37	Sirens	1.0	1.0	0.8
38	Left turn clip	1.5	1.2	1.0
40	Wrong driveway	1.0	0.8	0.5
44	Wave to go	1.5	1.3	1.2
47	Turn into passer	2.0	0.4	0.8
48	Back into roadway	2.0	1.0	0.1
52 [A]	Tailgate	1.0	0.8	0.3
56 [A]	Distracted rear end	2.0	1.9	1.7
58 [A]	Avoidance, rear end	1.5	1.0	0.4
61 [A]	Pedal miss	1.0	0.5	0.2
62 [A]	Inattentive rear end	12.0	10.2	4.9
64 [A]	Stutter stop	2.0	1.6	0.7
66 [A]	Aggressive rear end	1.5	1.1	0.5
68 [A]	Maintenance	2.2	2.6	2.6
74 [A]	Slick road, rear end	6.0	4.7	2.3
75	Passing clip	2.5	2.0	1.3
76	Lane change right	2.2	2.1	1.5
78 [A]	Visibility rear end	2.0	1.7	1.6
79	Lane change left	2.0	1.4	0.7
80 [A]	Lane change rear end	1.0	0.5	0.2
82	Back track	1.2	0.6	0.2
83	U-turn	1.6	0.9	0.4
91	Inexperience, departure	2.0	3.4	6.5
92	Impaired, head-on	2.5	2.5	2.9
93	Slick road, head-on	1.2	1.4	2.1
94	Run red into left turner	1.0	1.1	0.9
96	Misjudgment, left turn	1.6	1.8	1.5
99	View obstructed left	1.2	1.3	1.2

Number	Name	% Crashed (14,507,000 cars)	% Direct Cost ($66066 M)	% Years Lost (2,059,000 yr.)
100	Miscellaneous	1.7	0.7	0.6
101	New	?	?	?

A Considered rear-end crashes

B Struck human accident

C Struck animal accident

2.3.8 Summary of Crash Statistics

Across these studies, rear-end crashes accounted for between 11% and 32% of all collisions and about 5% of all fatalities across these studies (see Table 2-7). The percentage differences across studies are due to the different aims of these studies rather than disagreements. The Knipling et al. (1993) and National Safety Council (1993) studies provide the best estimates of the magnitude of the rear-end crash problem, whereas the Campbell et al. (1990), IRPS (1975), and 44 Crashes (1996) accident figures are a result of the way the crash data was sampled based on the specific aims of each of these papers. The direct costs are approximately $17.5 billion a year. The functioning and life lost is about 317,086 per year.

Reference	% of All Crashes	% of Fatal Crashes
Knipling, et al.	23.4	4.7
National Safety Council	23.6	4.75
Campbell, et al.	11.2	
IRPS	14.8	
44 Crashes	32.2	

Table 2-7 Summary of Rear-End Collisions

2.4 Crash Scenario Selection

This section describes the selection of relevant crash scenarios that were used to establish the minimum functional requirements contained in Chapter 4.

Functional requirements refer to system performance parameters and include, for example:

- Specification levels for detection zone
- Target size
- Maximum reporting delay
- Crash alert timing
- Adjustability
- Crash alert modality

Those collisions that establish the FCW minimum requirements are called the *relevant crash scenarios*. These are the scenarios that involve vehicle-to-vehicle rear-end crashes. The relevant crash scenarios do not include any collisions due to causal factors such as road surface, lack of vehicle maintenance and physiological state of the driver (e.g., alcohol-impaired, ill). Monitoring of these causal factors is not an intended function of the FCW system. The FCW system may help drivers avoid or mitigate a portion of these crashes; however, prevention or mitigation of these crash scenarios are not defined as the primary focus of FCW systems. The FCW system may benefit other major crash types such as Roadway Departure (20% of all crashes), Intersection (30%), Backing (3%), and Opposite Direction (3%) crashes, when the obstacle(s) appears in the FCW detection zone. Again, however, prevention or mitigation of these crash types is not defined as the primary focus of FCW systems.

One consideration in selecting the scenarios that would be used to derive the functional requirements was the technical feasibility of the sensing system. A minimal number of assumptions were made in the selection process. No assumptions were made regarding the underlying sensing technology. At this time, three active sensing technologies are dominant within the crash avoidance community: millimeter wave radar, laser radar and machine vision.

For the purpose of generating a set of relevant scenarios, a reasonable range of values was assumed for the horizontal and vertical field of view (FOV) and the minimum and maximum ranges of the system. Practical (operational) millimeter wave radar and laser radar systems might have a horizontal FOV of up to ±15º; the horizontal FOV for a vision-based system might be ±30 to ±40º. Generally, the vertical FOV of FCW systems is at least 3º. A minimum range of 1 m is considered small and a maximum range of 200 m is considered large. Only scenarios that require sensor performance that does not significantly exceeding these values were considered.

The following analysis is based on the typology and causal factors presented in "44 Crashes" using the fundamental assumptions, purpose of an FCW system, and assumed customer expectations described in Section 2.1. The "44 Crashes" describes all type of crashes including Intersection, Rear End, Roadway Departure, Lane Change and Merge, Backing, and Opposite Direction. "44 Crashes" was employed because the crash analysis approach employed in this work allows one to more easily identify and prioritize the rear-end crash scenarios. These scenarios are somewhat unique in that they consider precipitating causes involving driver behavior (e.g., driver inattention).

It is assumed that the FCW system is only on the SV while selecting the relevant crash scenarios. The following questions were applied to each crash scenario:

- Would an FCW system observe the crash?
- Would an FCW crash alert help the driver avoid or mitigate an impending collision?
- Taking into consideration the frequency and severity of the crash type, should this scenario drive the minimum functional requirements?

If the answer is "yes" to each of the above questions, the scenario is assigned to Category I, which are considered directly relevant scenarios. All other scenarios are assigned to Category II, which are not considered directly relevant scenarios. It is important to keep in mind that it is possible for an FCW system to benefit the driver in mitigating a portion of crashes in Category II, even though these crashes are not the primary emphasis of the system's design.

2.4.1 Crash Scenario Categories

Each of the 44 crash types defined in "44 Crashes" was assigned to a single crash scenario category. The two categories are defined as follows:

- **Category I (contribute to system requirements):** An FCW system will detect the other vehicles and may help the driver avoid or mitigate an impending collision for the *relevant scenarios* (as Category I crashes are referred to in other parts of this report). These scenarios will contribute to the minimum functional requirements for the FCW system.
- **Category II (do not contribute to system requirements):** These scenarios do not establish FCW minimum functional requirements. However, an FCW system may help the driver mitigate an impending collision for some of these scenarios in a limited capacity. While prevention or mitigation of these crashes is not an intended function of the FCW system, these crash scenarios may benefit from the FCW system.

2.4.1.1 Category I (Contribute to System Requirements)

A total of six crash scenarios from the "44 Crashes" fit the description of Category I. These scenarios and the rationale for grouping them into Category I are described below. Each scenario contributes to a problem-driven set of minimum functional requirements for an FCW system. These requirements were balanced against technology constraints and combined with other operational requirements discussed in Section 2.5 of this chapter to obtain the final set of minimum performance requirements.

According to Knipling, et al, rear-end crashes are 23% of all police reported crashes and 5% of all fatal crashes. 90% are on straight, level roads, 79% on dry roads and 77% in daylight. 70% occur with the lead vehicle stopped. 66% of the RE collisions occur due to inattention and driving too close.

Inattentive Rear-End Collision (#62 in Table 2-5)

This crash accounts for 12.0% of the total crashes, 4.9% of the functional years lost and 10.2% of the direct costs. This scenario contributes to the following minimum requirements: minimum headway, detection zone shape and size, target class, crash alert timing and crash alert modality.

Distracted Rear-End Collision (#56)

This crash accounts for 2.% of the total crashes, 1.7% of the functional years lost and 1.9% of the direct costs. This scenario contributes to the following minimum requirements: minimum headway, detection zone shape and size, target class, crash alert timing and crash alert modality.

Visibility Rear-End Collision (#78)

This crash accounts for 2% of the total crashes, 1.6% of the functional years lost and 1.7% of the direct costs. This scenario contributes to the following minimum requirements: weather capability, day and night operation and crash alert timing and adjustability.

Aggressive Rear-End Collision (#66)

This crash accounts for 1.5% of the total crashes, 0.5% of the functional years lost and 1.1% of the direct costs. This scenario may influence the following minimum requirements: minimum headway, detection zone shape and size, target class and adjustability.

Tailgate (#52)

This crash accounts for 1% of the total crashes, 0.3% of the functional years lost, and 0.8% of the direct costs. This scenario may influence the following minimum requirements: minimum headway, crash alert timing, adjustability and crash alert modality.

Lane Change, Rear-End Collision (#80)

This crash accounts for 1% of the total crashes, 0.2% of the functional years lost and 0.5% of the direct costs. This scenario may influence the following minimum requirements: minimum headway, detection zone shape and size, target class, crash alert timing and crash alert modality.

2.4.1.2 Category II (Do not Contribute to System Requirements)

A total of 36 crash scenarios from "44 Crashes" fit the description of Category II. These scenarios and the rationale for grouping them into Category II are described below.

Struck Human (#1 in Table 2-5)

Due to the severity of this crash type, it is desirable that an FCW help the driver avoid or mitigate this type of collision. However, many cases within this scenario are not solvable due to lack of warning time and obscured vision. For example, if a person suddenly intrudes in front of a moving vehicle, the system may not have adequate time to detect the obstacle and provide a warning to the driver. Similarly, a person crossing the street between two parked cars may be obscured from the sensor's view, so that there is inadequate time to provide a warning. Since it was judged the FCW system could not reliably detect humans at an adequate range, the driver would be left with ambiguous expectations with respect to a "pedestrian avoidance" capability, which would violate the notion of a simple mental model to the driver. This requirement to reliably sense pedestrians is not considered technically feasible at this point in a time, and hence, such a requirement could delay FCW system deployment. It should be noted that although the FCW system is not targeted for pedestrians, it still may provide benefits in some situations.

Struck Animal (#3)

Due to the frequency of this crash type, it is desirable that FCW systems help the driver avoid or mitigate this type of collision. However, many cases within this scenario are not solvable due to lack of warning time, obscured vision and difficulty in predicting the path of animals. The identical comments made above for "pedestrian avoidance" capability apply here to "animal avoidance" capability.

Drowsy Driver (#9)

Avoidance or mitigation may require additional capabilities, such as lane sensing and monitoring of driver physiological state, which are outside the scope of the FCW system capability assumptions described in Section 2.1.

Departures: Aggressive (#10); Slick Road (#11); Rough Road (#12); Impaired (#18); Inexperience (#91)

Avoidance or mitigation may require capabilities, such as lane sensing, which are beyond the FCW system capability described in Section 2.1. In addition, the driver of the SV may have already lost control of the vehicle, so a warning may not help the situation.

Avoidance Departure (#13)

When an obstacle(s) suddenly appears in the SV path, the FCW system may not have adequate time to detect the obstacle and provide a warning to the driver.

Back into Object (#19); Back into roadway (#48)

Obstacles under consideration are not in the forward detection zone.

Ran Red "T-bone" (#22)

Avoidance or mitigation of this scenario may require a wider detection zone than the FCW system capability described in Section 2.1. When the FCW system observes the POV at a close range, avoidance or mitigation may not be possible due to lack of warning time.

Slick Road, Ran Stop (#28); Slick Road Head On (# 93)

Avoidance or mitigation of this scenario requires monitoring of road surface conditions, which is beyond the FCW system capability described in Section 2.1.

Inattentive, Ran Stop (#30)

Avoidance of this scenario requires a wide forward coverage zone (up to 180 degrees) and identification of stop signs, which is beyond the model FCW system described in Section 2.1.

View Obstruction (#33); View Obstruction Left (#99)

When driver's view is obstructed, the FCW system's view may also obstructed.

Look but Did Not See (#35); Sirens (#37); Left Turn Clip (#38)

Avoidance of this scenario requires a wide forward coverage zone (up to 180 degrees), which is beyond the model FCW system described in Section 2.1.

Wrong driveway (#40); Wave to Go (#44), Run Red into Left Turner (#94), Misjudgment Left Turner (#96)

Avoidance or mitigation is not possible since the POV is not in the SV detection zone.

Turn into Passer (#47); Lane Change, Right and Left (#76, 79)

Avoidance or mitigation of this scenario may require side-sensing capability, which is not an intended function of FCW systems.

Avoidance Rear End (#58)

The lead vehicle obstructs the SV's view of the POV in the adjacent lane. Therefore, the SV driver may be unable to avoid or mitigate an impeding collision due to lack of warning time even though the FCW system may detect the POV after the SV changes lanes.

Pedal Miss (#61)

An FCW system may warn the driver when the POV is in the SV detection zone. The driver has already attempted to avoid or mitigate an impeding collision; however, he/she has missed the pedal.

Stutter Stop (#64)

Avoidance of this scenario may not be possible due to lack of time and requiring the FCW system to operate at extremely close range.

Maintenance (#68)

Avoidance or mitigation of this scenario requires monitoring of vehicle conditions such as brake or tire pressure, which is not an intended function of FCW systems.

Slick Road, Rear End (#74)

The SV will detect the POV when the POV is in the SV path; however, avoidance or mitigation may not be possible due to lack of warning time resulting from the road surface condition. Monitoring of road surface conditions is not a function of the FCW system capability described in Section 2.1.

Passing Clip (#75)

Avoidance of this scenario may require a wide forward coverage (up to 180 degrees), which is outside the practical limits discussed in Section 2.1.

Back Track (#82)

An FCW system may be able to provide a warning to the SV driver; however, the SV driver has limited ability to avoid or mitigate the impending collision.

U-Turn (#83)

The SV may detect the POV; however, avoidance or mitigation may not be possible due to lack of warning time.

Impaired, Head On (#92)

Even though an FCW system may warn the SV driver about the impending collision, avoidance or mitigation may not be possible due to lack of warning time. This situation occurs because of the extremely high closing speeds involved in this crash type and the limited sensing range of an FCW system. It has been suggested that the FCW system may be beneficial in some instances of this crash type since there may be adequate warning time for the driver to perform an avoidance maneuver (rather than attempting full braking). However, this crash scenario is included in Category II because of the limited number of cases in which the FCW system may be of benefit and the impractical demands that addressing this scenario, places on system technology.

Finally, two crashes do not belong in either category: Miscellaneous (#100) and New (#101). Table 2-8 gives the tabulated results of applying this procedure to “44 Crash” scenarios.

Number	Name	Category I (Scenarios that contribute to FCW functional requirements)	Category II (Scenarios that DO NOT contribute to FCW functional requirements)
1	Struck human		X
3	Struck animal		X
9	Drowsy driver		X
10	Aggressive departure		X
11	Slick road departure		X
12	Rough road departure		X
13	Avoidance departure		X
18	Impaired departure		X
19	Back into object		X
22	Ran red “T-bone”		X
28	Slick road, ran stop		X
30	Inattentive, ran stop		X
33	View obstruction		X
35	Looked but didn’t see		X
37	Sirens		X
38	Left turn clip		X
40	Wrong driveway		X
44	Wave to go		X
47	Turn into passer		X
48	Back into roadway		X
52	Tailgate	X	
56	Distracted rear end	X	
58	Avoidance rear end		X
61	Pedal miss		X
62	Inattentive rear end	X	
64	Stutter stop		X
66	Aggressive rear end	X	
68	Maintenance		X
74	Slick road rear end		X
75	Passing clip		X
76	Lane change right		X
78	Visibility rear end	X	
79	Lane change left		X
80	Lane change rear end	X	
82	Back track		X
83	U-turn		X
91	Inexperience, departure		X
92	Impaired, head-on		X
93	Slick road, head-on		X
94	Run red into left turner		X
96	Misjudgment, left turn		X
99	View obstructed left		X

Table 2-8 Generation of Relevant Scenarios to Establish FCW Functional Requirements

2.4.2 Summary

Table 2-9 summarizes the six relevant scenarios and the FCW functional requirements to which they contribute, and lists these scenarios in order by the percentage of direct cost attributable and the percentage of functional years lost attributable to each crash scenario.

These six relevant scenarios account for approximately 19.5% of all annual crashes in the United States, approximately 16.2% of the direct costs, and approximately 9.2% of the functional years lost. These percentages suggest that a sizable portion of the crash problem may be addressed through the use of FCW systems possessing characteristics similar to the model system described in Section 2.1 of this report.

Of these six relevant scenarios, Inattentive RE appears to offer the major opportunities for benefits from FCW systems; this scenario accounts for about 63% of the direct cost and 53% of the functional years lost attributable to the combined relevant scenarios. However, this is an ideal model, and it is recognized that no crash avoidance system can be 100% effective at preventing a particular crash type. On the other hand, an FCW system may provide benefit in the Category II crash scenarios as well.

Number	Name	Frequency (%)	Functional Years Lost (%)	Direct Cost (%)	Key Parameters
62	Inattentive RE	12.0	4.9	10.2	Minimum headway, detection zone shape and size, target class, warning modality
56	Distracted RE	2.0	1.7	1.9	Minimum headway, detection zone shape and size, target class, warning modality
78	Visibility RE	2.0	1.6	1.7	Weather capability, day and night operation, separation criteria adjustability
66	Aggressive RE	1.5	0.5	1.1	Minimum headway, detection zone shape and size, target class, separation criteria adjustability
52	Tailgate	1.0	0.3	0.8	Minimum headway, warning distance, separation criteria adjustability, warning modality
80	Lane change RE	1.0	0.2	0.5	Minimum headway, detection zone shape and size, target class, warning modality

Table 2-9 Summary of Relevant Scenarios and Key Parameters

2.5 Operational Scenarios

While the purpose of an FCW system is to provide warnings to the driver when confronted by a relevant scenario, the response of the system to other common, non-crash operational scenarios is also extremely important. These operational scenarios were used to modify the functional requirements contributed by the relevant crash scenarios and resulted in additional requirements to the overall minimum functional requirements. It is widely believed that a high incidence of nuisance alerts will erode driver confidence in an FCW system and could lead drivers to modify their reactions to appropriate warnings (Farber and Paley, 1993; Lerner et. al, 1996; Wilson 1994). 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 an FCW system when drivers do not consider the situation alarming. Three types of nuisance alerts can be distinguished.

- *False alerts* caused by noise or interference, when there is no object present.
- *In-path nuisance alerts* are those caused by vehicles that are in the path of the SV but are at a distance or moving at a speed that drivers do not perceive as alarming.
- *Out-of-path nuisance alerts* are those caused by objects that are not in the path of the subject vehicle.

	No Obstacle	**In-Path Vehicle**		**Out-Of-Path Objects**
		Alarming Situation	**Non-Alarming Situation**	
Alert Occurred	False alert	Appropriate alert	In-path nuisance alert	Out-of-path nuisance alert
No Alert Occurred	Appropriate non-alert	Missed alert	Appropriate non-alert	Appropriate non-alert

Table 2-10 Decision Type Matrix for Forward-Collision Warning System

Table 2-10 summarizes the types of nuisance alerts and their relationship with the driver's perception of the situation. It also includes *missed alerts,* which are those that do not occur or occur too late to be useful. While no quantitative data is publicly available regarding acceptable nuisance, false and missed alert rates, minimizing their number represents a major challenge to fielding FCW technology given the current state-of-the-art.

The following list identifies some common operational scenarios that could cause FCW systems to miss alerts or generate nuisance alerts. The scenario categories are listed below.

- Overhead objects
- The road surface itself and debris on the road
- Adjacent lane traffic
- Roadside clutter
- Diverse vehicle sizes
- Lane changes

Each category will now be discussed in turn.

2.5.1 Overhead Objects

Obstacles above the roadway may be interpreted as being in the path of the vehicle and cause an out-of-path nuisance alert. Overhead items that may affect the system are overpasses, suspended bridges, signs and traffic lights. The vertical field of view of an FCW system and its range will determine if this category would contribute to the nuisance warnings. This category contributes to the minimum requirements addressing detection zone shape and size.

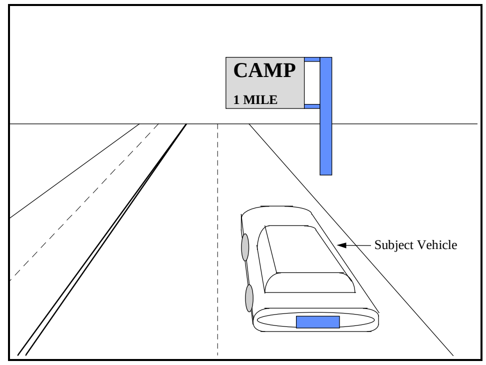

Figure 2-2 Overhead Obstacle

2.5.2 Road Surface and Debris

Different road surfaces may cause nuisance alerts. Metallic manhole covers and grated metal surfaces (as found on bridges) may give a false warning of an obstacle ahead. Similarly, surface markings such as signs, crosswalks, painted lane stripes and retroreflectors on the road surface may confuse some systems. Debris such as tire scraps, soda cans or pieces of wood may also be misinterpreted. Going up or down a hill may make the FCW system interpret the road incorrectly and give a warning when none is required. An example would be a steep driveway where the FCW system is directed down at the road surface ahead, as shown in Figure 2-3. This category contributes to the minimum requirements addressing detection zone shape and size, vertical curvature tolerance and target sizes.

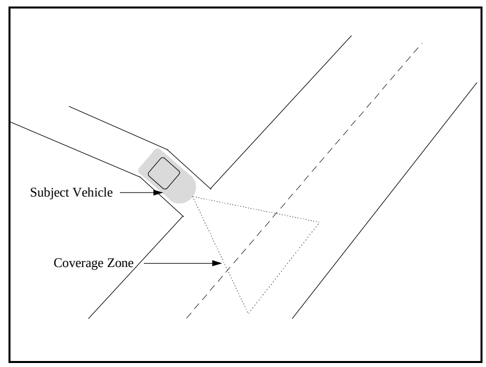

Figure 2-3 Steep Hill Scenario

2.5.3 Adjacent Lane Traffic

Figure 2-5 illustrates how a vehicle in an adjacent lane to the subject vehicle is directly ahead when the roadway bends to the right or left. The system may interpret these vehicles as being

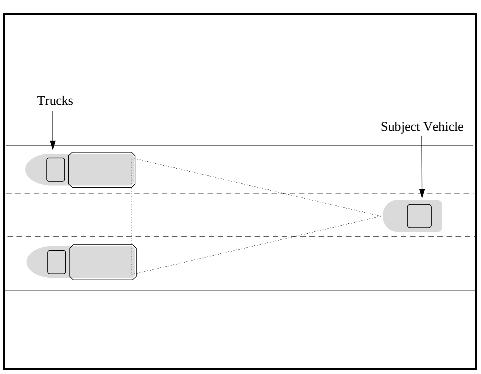

Figure 2-4 Adjacent Vehicles

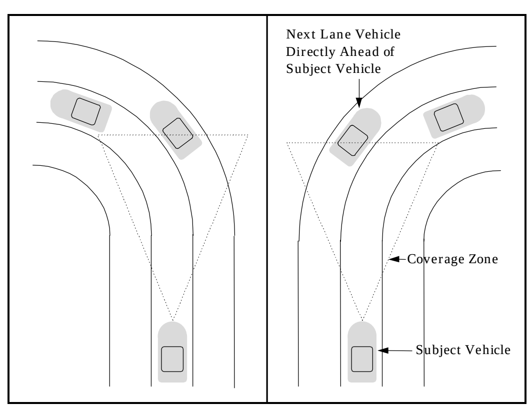

Figure 2-5 Adjacent Lane

in the path of the subject vehicle and alert the driver when it is not necessary. Figure 2-4 illustrates a situation where vehicles in adjacent lanes may be mistaken for a single vehicle in the same lane as the subject vehicle. Each of these situations relates to out-of-path nuisance alerts. This category contributes to the minimum requirements addressing roadway horizontal curvature and POV sizes.

2.5.4 Roadside Clutter

As shown in Figure 2-7, objects outside the SV's path on a curved roadway, such as guardrails, trees, rocks or road signs, may appear in the detection zone of an FCW system. The system may interpret the object as being in the vehicle's path and alert the driver unnecessarily. This situation is common in a "U-Turn in Median", in which drivers typically decelerate hard into a lane in which a large metallic sign resides outside the curve of this reversal lane. Narrow streets with parked cars or mailboxes and lampposts close to road edges, as in urban areas, present obstacles close to the FCW system coverage zone, Figure 2-6. This would cause out-of-path nuisance alerts, as shown in Table 2-10. This category contributes to the minimum requirements addressing detection zone shape and size, and target classes.

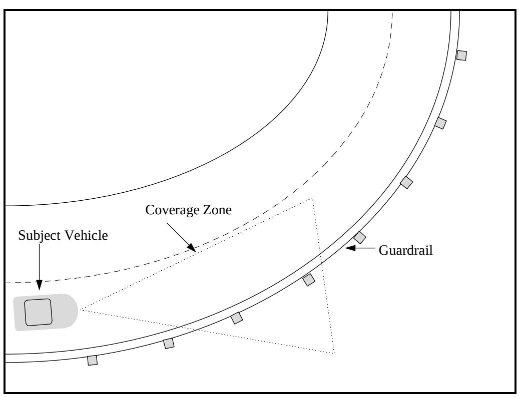

Figure 2-7 Curved Road Scenario

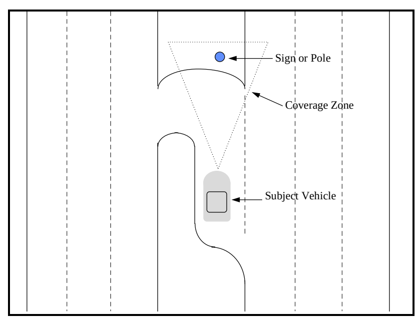

Figure 2-8 U-Turn in Median

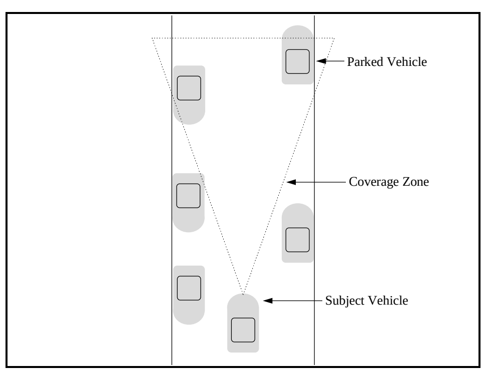

Figure 2-6 Dense Clutter Environment

2.5.5 Diverse Vehicle Sizes

Complex traffic situations may contribute to a “Missed Alert”, defined in Table 2-10.

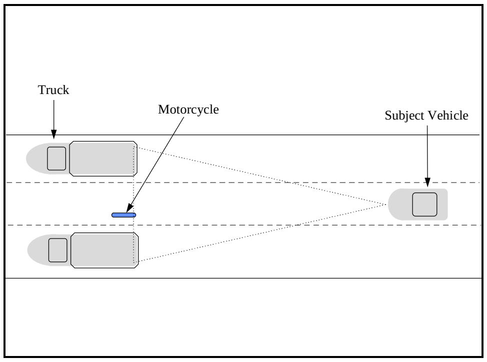

Figure 2-9 Greater Size and Equal Distance

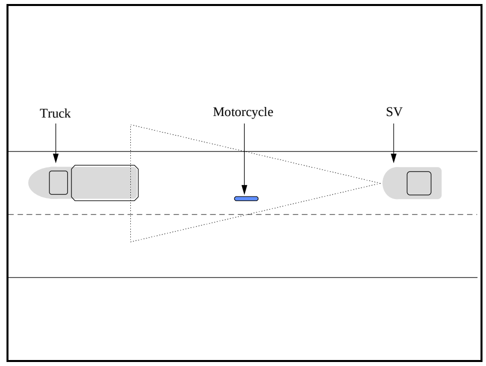

Figure 2-10 Greater Size and Distance

The obstacle that is in the path of the SV may be overlooked due to a larger obstacle at a greater or equal distance, Figure 2-9 or Figure 2-10. This category contributes to the minimum requirement addressing target classes.

2.6 Summary

A set of relevant scenarios were selected that describe the primary crash situations selected for the purpose of generating FCW system functional requirements. In addition, a set of operational scenarios was identified that describe non-crash situations in which FCW systems should not generate nuisance alerts. Together, these roadway scenarios form the basis for developing the minimum functional requirements and objective test procedures for FCW systems.

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CHAPTER 3

DEVELOPING A FCW SYSTEM CRASH ALERT TIMING AND MODALITY APPROACH VIA HUMAN FACTORS STUDIES

TABLE OF CONTENTS

List of Figures

List of Tables

3 DEVELOPING A FCW SYSTEM CRASH ALERT TIMING AND MODALITY APPROACH VIA HUMAN FACTORS STUDIES

3.1 Preface

The goal of the human factor portion of the CAMP project was to define driver-interface requirements. More specifically, this effort is focused on defining when to present crash alerts (i.e., crash alert timing) and how to present crash alerts to drivers (i.e., the crash alert modality).

The need for obtaining data to define these requirements was dictated by the absence of data under controlled, realistic conditions involving drivers braking to a realistic crash threat. Based primarily on the four closed-courses, human factors studies described in this chapter, a set of minimum driver interface requirements and recommendations were developed, which are discussed in Chapter 4.

The current chapter is conceptually organized into two parts. The first part of this chapter is encompassed by Study 1, referred to as the "baseline study". This study was aimed at defining crash alert timing for subsequent studies, and asked drivers to perform "last-second" braking maneuvers without FCW system support. The second part of this Chapter is encompassed by Study 2, Study 3, and Study 4, which are collectively referred to as the "Interface Studies". These studies were aimed at defining how to present FCW system crash alerts to drivers, and provided the opportunity to evaluate and validate the crash alert timing approach developed in the baseline study. In these studies, drivers experienced various FCW system crash alert types under both expected and unexpected (surprise) lead vehicle braking conditions. In 2 of these 3 interface studies, drivers were completely unaware the vehicle was equipped with FCW system crash alerts when the surprise-braking event was introduced.

The reader interested in a collective summary (or overview) of both the baseline study and the interface studies is referred to the Executive Summary at the very beginning of this report.

3.2 Abstract for Study 1 – The Baseline Study

The goal of the human factor portion of the CAMP project was to define driver-interface requirements. More specifically, this effort is focused on defining when to present crash alerts (i.e., crash alert timing) and how to present crash alerts to drivers (i.e., the crash alert modality. The primary goal of this first CAMP human factor study was to define a crash alert timing approach for a FCW system by exploring various driver behavior measures.

In this 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

of this experimental strategy is that properly characterizing (i.e., modeling) the kinematic conditions surrounding the 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.

More specifically, in developing a crash alert timing approach for a FCW system, two fundamental driver behavior parameters have to be considered. These parameters serve as input into straightforward vehicle kinematic equations that determine the alert range necessary to avoid a crash. The first parameter is the time it takes for the driver to respond to the crash alert and begin braking (which includes *driver brake reaction time*), and the second parameter is the driver deceleration (or braking) behavior in response to this alert across a wide variety of initial vehicle-to-vehicle kinematic conditions. This second parameter was addressed by the current study.

Under closed-course conditions, drivers were asked to wait to brake until the last possible moment in order to avoid colliding with the “surrogate” lead vehicle, which was either slowing or stopped. This lead vehicle was designed to mimic a real vehicle as much as possible with the constraint it would allow for safe impacts at low impact velocities. The experimenter had access to add-on brakes and an audible crash alert. Thirty-six younger, 36 middle-aged, and 36 older drivers were tested. Overall, data from over 3,800 last second braking trials were obtained. The critical need for obtaining this type of data under controlled conditions is dictated by the infrequency of near/actual rear-end crashes (and associated “black box” data), the lack of data available to support FCW “benefits” modeling, and the inherent difficulties associated with accident reconstruction.

Converging evidence suggests that the 50th percentile required deceleration value observed in this study under “hard braking” driver instructions appears very promising as an appropriate (not too early/not too late) estimate of the assumed driver braking onset range 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). To 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, which is in sharp contrast to the “constant (or fixed) driver deceleration level” assumption routinely employed in FCW warning algorithms and “benefits” modeling. It is also important to note that these required deceleration values were relatively uninfluenced by driver age or gender, which is a desirable finding from a production implementation perspective. Additional evidence suggest 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.

In terms of allowing the driver sufficient warning distances to avoid a crash, 100 meters of sensor “knowledge” accommodated over 90% of drivers in all the various testing conditions, except when drivers approached a parked vehicle at 60 mph (the highest delta velocity condition tested). There are several caveats associated with this conclusion, including an assumed 1.7 second combined driver perception reaction time plus delay time, that sufficient road surface coefficient of friction is available (dry roads were used here), and that drivers can match the observed hard braking levels during real-world braking in response to a crash alert.

These results also suggest that attempts to define crash alert timing based on research which places drivers under minimal crash risk or no crash risk (e.g., simulator) conditions has potential to lead to overly aggressive crash alert timing. This research approach could in turn lead to the consequence of decreasing the harm reduction potential of the FCW system. In addition, these results raise serious concerns about the real-world validity of previous FCW interface research.

The results of this study were used in the three subsequent driver interface studies for crash alert timing purposes. More specifically, these results, and the subsequent modeling of these Study 1 results (see Appendix A20) aimed at predicting required deceleration values, formed the basis for assumptions regarding the assumed driver deceleration (or braking) behavior in response to the FCW crash alert in the subsequent driver interface studies. These interface studies focused on how to present a crash alert to the driver (i.e., visual, auditory, and/or haptic alerts), and provided an important opportunity to evaluate and validate these deceleration-based crash alert timing approach assumptions.

3.3 Study 1 - “Last-Second” Braking Judgments Without FCW Crash Alerts

3.3.1 Introduction

This research described here is the first of four closed-course, field studies aimed at exploring human factors issues surrounding FCW systems (i.e., the effects of the FCW system and associated interfaces on driver behavior). More specifically, this research will explore human factors issues surrounding FCW which has not been adequately addressed by the relatively limited number of previous human factors studies, which have been conducted either under laboratory conditions (Graham, Hirst, & Carter, 1995; Hirst & Graham, in press) or driving simulator conditions (Janssen & Nilsson, 1990; Janssen & Thomas, 1994; McGehee, Dingus, & Wilson, 1996; Nilsson, Alm, & Janssen, 1991).

The primary goal of this first CAMP study was to develop a crash alert timing approach for a FCW system by exploring a number of performance measures. In this 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 of this experimental strategy is that properly characterizing (i.e., modeling) the kinematic conditions surrounding these 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.

The three follow-on CAMP human factors studies involve examining driver behavior *with a FCW interface*, in the context of the solid foundation for a crash alert timing approach provided by the present study.

More specifically, in developing a crash alert timing approach for a FCW system, two fundamental parameters involving driver behavior have to be considered. One parameter is the time it takes for the driver to respond to the crash alert and begin braking, referred to as *driver brake reaction time* (or driver brake RT). This parameter was not addressed in the current study, and will be addressed in planned follow-on studies, which will include unexpected braking events. A second parameter involving driver behavior is the assumed braking onset range (which may be expressed either by deceleration-based and/or time-based measures), once the driver has responded to the crash alert and begins to apply the brake. This second parameter was the focus of this study.

Overview of Methodological Approach

Overall, the goal of the current study (and subsequent CAMP studies) is to gather data of the highest real-world validity possible under controlled closed-course conditions. Consistent with this strategic approach, the experimental methodology employed for the current study is aptly described in the following quotation.

> One should not ask subjects to indicate the hypothetical moment they would collide, or the moment an evasive action has to start. Let them perform as if in actual traffic and record when they make their decision and how they react. (van der Horst, 1990, p. 133)

Under closed-course conditions, the current study asked drivers to make last-second braking judgments and maneuvers to a slowing or stopped “surrogate” lead vehicle. This surrogate lead vehicle was designed to mimic a real vehicle as much as possible with the constraint that the surrogate lead vehicle would allow for safe impacts at low impact velocities (up to 10 mph). The passenger-side experimenter had access to add-on brakes and an audible collision alert. Younger, middle-aged, and older drivers were tested. Overall, data from over 3,800 last-second braking trials were obtained. The critical need for obtaining this type of data under controlled conditions is dictated by the infrequency of near and actual collisions in the real-world, the sparseness of “black box” data available during these situations, the lack of data available to support collision warning “benefits” modeling, and the inherent difficulties involved in precisely reconstructing an accident.

3.3.2 Experimental Methodology and Approach

Subjects

Test participants consisted of 18 males and 18 females in each of three different age groups: 20-30 , 40-51, and 60-71 years old. Corresponding mean ages for these younger, middle-aged, and older age groups were 25, 46, and 65 years old, respectively. Each driver was tested individually in one approximately 2 to 2 ½ hour session and paid $150 for their participation. Drivers were recruited by an outside market research recruiting firm, and were required to be within approximately a 45-minute drive from the Milford Proving Ground facility. (Hence, for some participants, the test involved a 4-hour time commitment.) Two drivers, both in the older age group, were not able to complete the test due to feeling uneasy or ill.

Drivers who were ultimately allowed to participate were mailed the information letter shown in Appendix A prior to testing. A copy of the informed consent statement, which describes the various conditions that ruled out potential drivers from participating, is also provided in Appendix A. Participants were required to possess a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of 2 years driving experience, be over 18 years of age, be able to drive an automatic transmission vehicle without assisting devices or special equipment, be able to give informed consent, and not be under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair their ability to drive. Drivers were also excluded from participation if they had a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, obvious shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or were pregnant. Additionally, participants were asked to refrain from the use of alcohol, drugs, or any other substances (e.g., antihistamines) which impair their ability to drive for a period of no less than 24 hours prior to participation. Finally, drivers were excluded if anyone in their household worked for an automobile dealer, manufacturer or supplier, an advertising agency, a TV or radio station, a newspaper or magazine publisher, or a market research firm or department.

Test Site

Data was gathered on a 1 mile long, 2 lane wide (12 foot wide lanes), straight, level, smooth asphalt road at the General Motors Milford Proving Ground in Milford, Michigan. The road was closed to all other traffic during testing, and is shown in Figure 3-1. All testing was conducted under daytime conditions under generally dry road and dry weather conditions.

Test Vehicles and the "Surrogate" (Lead Vehicle) Target

Overview of Experimental Apparatus

Test participants were asked to drive behind the lead vehicle, which towed (at about 40 feet behind) a 3-dimensional mock-up of the rear-end of a 1997 Mercury Sable. The driver's (or subject's) vehicle, the mock-up surrogate lead-vehicle, and the lead (tow) vehicle will be subsequently referred to as the *subject vehicle (SV)*, *surrogate target*, and *principle other vehicle (POV)*, respectively. These three elements of the experimental set-up are shown in Figure 3-1 and Figure 3-2. Both the SV and POV were 1997 Ford Taurus SHOs equipped with driver-side airbags and anti-lock brakes. Both the SV and POV were driven by trained Milford Proving Ground test drivers, who were from the General Motors Proving Ground Special Tests Group and had previous experience conducting brake tests. The SV and the POV test drivers communicated during the study via FM radio communication.

Surrogate (Lead Vehicle) Target

The surrogate lead vehicle target was designed to mimic a real vehicle as much as possible with the constraint that, if struck at low speeds (up to 10 mph impact speeds), it would not cause injury to either the test participant or researchers, or damage to the target. Several illustrations of the surrogate target are provided in Figure 3-1 through Figure 3-5. A detailed description of the design of the surrogate target is provided with kind permission from Roush Industries, Inc in Appendix A, at the end of this final report. The basic components of the target include a "skin" made of a flexible polyurethane material, a supporting PVC frame, a trailer assembly (with mild steel tubing), coiled springs attached to a high density foam bumper, a collapsible beam (which could collapse up to 9 feet), working rear lighting, and reflectors (for range sensing purposes).

Figure 3-1 Side View of the Principal Other Vehicle (POV), Surrogate Target (Or Surrogate Lead Vehicle) and Subject Vehicle (SV), as well as an Illustration of the Test Track

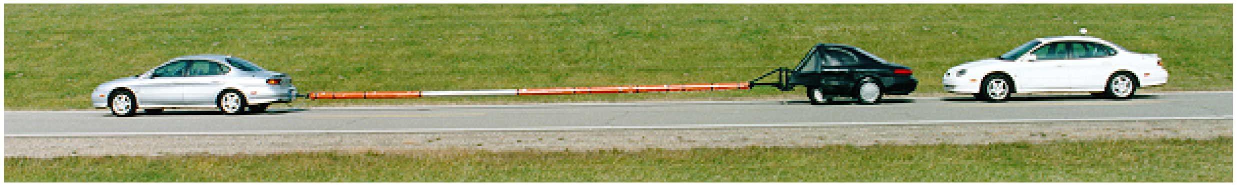


Figure 3-2 Side View of the Principal Other Vehicle (POV), Collapsible Beam, Surrogate Target and Subject Vehicle (SV)

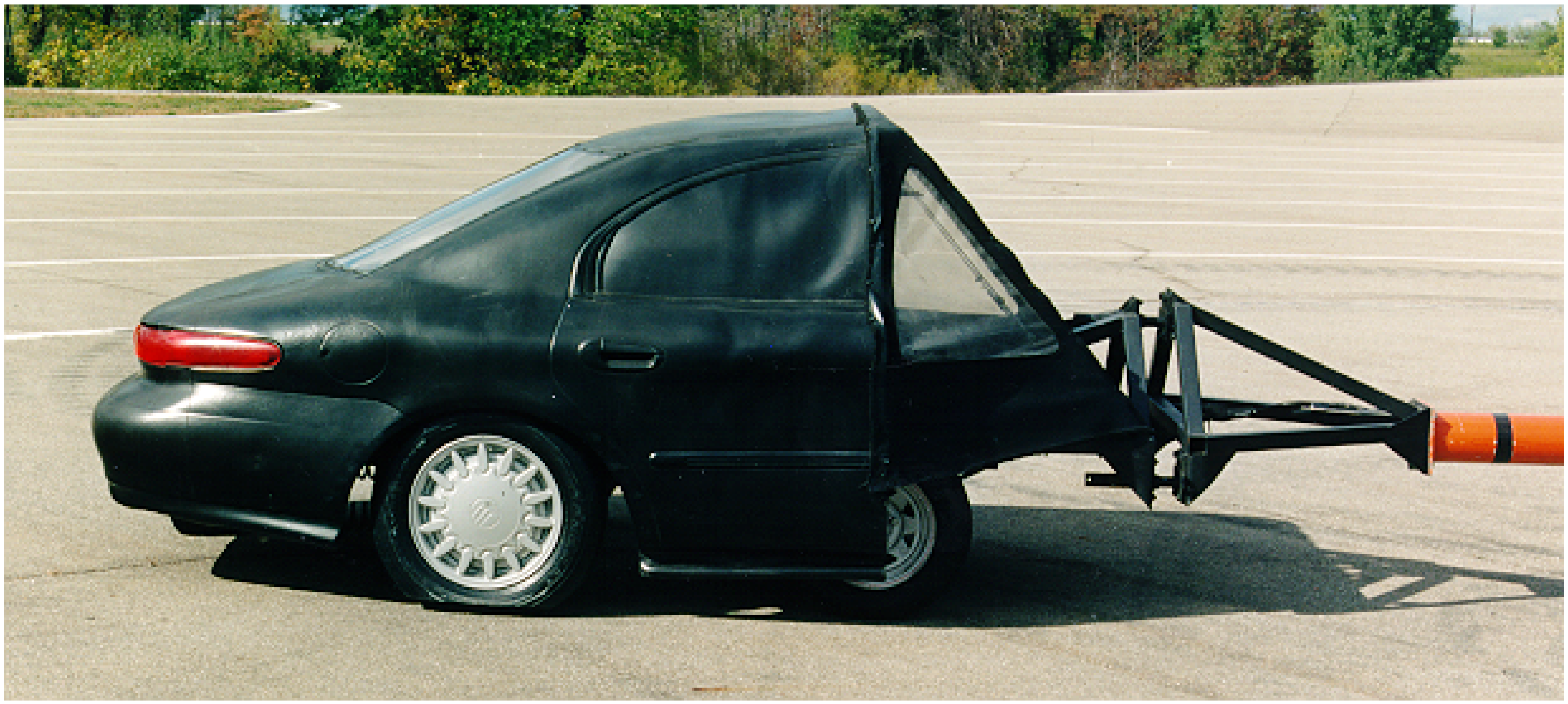


Figure 3-3 Close-Up Side View of the Surrogate Target

Figure 3-4 Close-up Rear View of the Surrogate Target

Figure 3-5 Close-up Front View of the Surrogate Target

In order to ensure the safety of the test participants and research team, a surrogate target validation crash impact test was conducted at the GM Safety Test Laboratory where full-scale barrier tests are routinely conducted. The general philosophy of this test was to stage dynamic SV/POV impacts (with the POV stationary) by gradually increasing the SV approach speed until the surrogate target incurred sufficient damage to warrant replacing the target. At this delta velocity (i.e., the difference in speeds between the SV and POV) level, the purpose of the test was to ensure that neither the SV or POV experienced any damage, and that the surrogate target crash impact would not reach the criterion for triggering the driver-side airbag in the SV.

Four crash tests were conducted (in the following order), with impacts of 5.3, 7.5, 10.6, and 10.6 mph, respectively. During the first and fourth test, the SV brakes were not applied. During the second and third tests, only the SV parking brake (i.e., rear brakes) was applied. Results indicated the following. First, the air bag was not activated during any of the four crashes. Second, across tests, only cosmetic SV front bumper damage was obtained, which was the result of the SV hitting a metal vertical plate within the body cavity of the surrogate target, which then pushed the surrogate target forward (which resulted in the collapsible beam collapsing). Across tests, the collapsible beam attaching the POV and surrogate target, which can collapse up to about nine feet, never collapsed more than about 31 inches (about 2 ½ feet). Third, the integrity of the surrogate target remained largely intact across tests. Fourth, there was a tendency for the surrogate target to climb onto the front hood (although it never touched the windshield), particularly at the highest impact speed with no brakes applied. In order to mitigate this tendency, the target was subsequently modified. These modifications involved adding to the rear of the surrogate target a high-density Styrofoam bumper and four coiled springs. In addition, in order to prevent sagging of the target, the target was reinforced with fiberglass in certain areas.

Subsequent “live” surrogate target validation crash tests were performed with a driver and passenger approaching the parked “modified” surrogate target at 5 and 10 mph speeds. These tests resulted in no damage to either the surrogate targets or the test vehicles, and provided strong support that the modifications eliminated any tendency for the surrogate target to climb onto the front hood. In addition, during further pilot testing, the torque of the collapsible beam was loosened up until the point the stability of the surrogate target was not compromised when the POV braked at a -0.45 g deceleration level at the highest test speed (60 mph).

In order to prevent the test participants from experiencing surrogate target impacts above the highest desirable delta velocity, the passenger-experimenter was provided an add-on brake and a “bail-out” FCW crash alert (described later). This alert was used to signal the passenger-experimenter to take over and begin braking. Overall, during formal data collection (i.e., 3,888 last second braking judgment trials), six impacts occurred with the surrogate target. Four of these impacts were relatively minor, and the remaining 2 impacts resulted in the beam collapsing from 1½-2½ feet. Although a spare surrogate target was available, the original target was never replaced during the entire test.

Data Acquisition System

Equipment Overview

The SV and POV were instrumented to continuously record various measures at 30 Hz, including the range (or distance) between the two vehicles, and the speed and acceleration of both test vehicles. All equipment was secured as not to present a hazard. Modifications to the SV included the installation of the following devices: brake pressure sensors (brake pedal load cells), accelerometer, GPS receiver, data logger, inverter, laptop computer, laser radar sensor, video recorder, video splitter, three cameras, and a steering sensor. In addition, a passenger-side override brake pedal, mechanically linked to the driver's brake pedal, was installed on the front passenger's side. Modifications to the POV included the installation of the following devices: brake pressure sensors, accelerometer, GPS receiver, data logger, inverter, laptop computer, smart brake booster, throttle controller, and control for the electric brakes on the trailer. The POV was instrumented such that the POV could automatically brake at a pre-selected constant deceleration value. A rear looking, eye-safe, ranging sensor was also installed on the POV. A conventional trailer hitch was added to the back of the POV, in order to tow the surrogate target. The data logging system, power inverters, and batteries were installed in the trunk and securely fastened to prevent shifting during the testing. A fire extinguisher, first-aid kit, and an FM radio communication system was placed in both test vehicles. A cellular phone was located in the POV.

Software

Data collection and control software was developed using a LABVIEW product. GPS time was used to synchronize the data from both vehicles and the video. Special care was taken to record time on each video frame to synchronize with the data during play back. The user was provided with current information about vehicle performance on the screen of the computer during the testing. The user was able to start and end a test sequence with a single keystroke. The software program was the same for both vehicles. The functions within the program were selectable depending on which vehicle it was used in. A setup file was used to configure the program for the vehicle. The basic differences between the POV and SV functions were the control of braking on the POV, and the control of video recording and audible alert on the SV.

Different POV braking profiles (i.e., constant deceleration profiles) were coded into setup files. The user determined when the profile would be executed for a given test from a single keystroke. The profiles were based on the vehicle speed condition and the POV braking. The software program used the Smart Booster and the accelerometer to control POV braking. The video recorder in the SV was controlled from the same keystroke that started and ended the test. The SV employed information provided by the laser radar sensor function to provide the experimenter an auditory crash alert corresponding to the last possible moment that braking must begin in order to avoid a collision with the surrogate target. The alert algorithm was part of the setup file.

"Bail Out" Crash Alert

The crash alert equation employed was the following (if range was less than the quantity on the right-hand side, the alert was sounded):

$$Range < (((V_{SV}-V_{POV})^2/2(a_{SV}-a_{POV})) + T_{SV}(V_{SV}-V_{POV}))$$

where: - V_{SV} *and* V_{POV} *are the measured velocities in m/s of the SV and POV, respectively*
- a_{SV} *is the assumed SV (constant) deceleration value, which was 6.9* m/s^2 *(-0.70 g's)*
- a_{POV} *is the assumed POV deceleration based on the trial condition, which was either -1.5, -2.9* m/s^2*, - 4.4* m/s^2*, (-0.15,-0.30, or -0.45 g's)*
- T_{SV} *is the assumed "travel" delay time value (includes test driver reaction time plus system delay time), which was assumed to be 1 seconds for POV Stationary Trials, and 2 seconds for POV Moving Trials*

Data Recording

All data parameters were recorded at a 30 Hz rate throughout the testing. Data was written to a file in a directory that was unique for that test. The directory names were based on the date and a sequence of run numbers for that day. The folder names were dependent on which vehicle the data was collected, 'RUNAxxx' for the SV and 'RUNBxxx' for the POV. The data was combined from each vehicle at the end of the testing into synchronized files. The combined data was placed into a folder 'RUNCxxx'. The combining process was based on the start and end time of each file for that day. At the beginning of each test, header information was recorded that identified the date, time, vehicle, and setup used.

Procedure and Design

Procedures Before and After Test Trials

After completing various pre-experiment forms and procedures (including the informed consent statement), drivers were escorted to the track. Drivers were then administered test instructions verbally (shown in Appendix A), and asked to adjust the seat, steering wheel, and mirrors to their preferred position, and to fasten their shoulder harness and lap belt.

Before starting testing, a brief review of instructions was again administered verbally (shown in Appendix A). It should be noted that drivers were instructed on the nature of the surrogate target, and more specifically, that this target was designed to allow low speed impacts. Next, a sequence of practice and test trials was conducted, described below. After the test trials were completed, drivers were escorted from the track, debriefed on the purpose of the study, and paid for their participation.

Overview of Test Trials / Driver Instructions

Drivers experienced trials in which the POV was parked (or stationary), and trials in which the POV was moving. These two general types of test trials will be referred to as *Stationary Trials* and *Moving Trials,* respectively. During Stationary Trials, drivers were asked to approach the parked surrogate target at an instructed speed, either 30, 45, or 60 mph. During Moving Trials, drivers followed a lead vehicle which towed the surrogate target at these same three speeds, and were given ample time to maintain and stabilize at what they considered to be their normal following distance. Next, the POV driver enabled the POV to automatically brake to a stop according to a pre-specified braking profile, which resulted in a constant deceleration of either -.15, -.28, or -.39 g's). (It should be noted that the original experimental design called for the two hardest POV braking profile level to be -0.30 and -0.45 g's respectively, but subsequent data analysis indicated that only a POV braking profile levels of -0.28 and -0.39 g's were attained for these two conditions during the study.) At that point, the test participant was asked to wait to brake the SV at the last possible moment in order to avoid colliding with the surrogate target. When both vehicles came to a complete stop, data collection was halted and the trial was ended. During Stationary Trials, drivers were asked to make these same braking judgments while approaching the parked surrogate target.

Drivers were asked to make these last second braking judgments under three different braking instruction conditions, "normal" braking, "comfortable hard" braking, and "hard" braking. Each instruction differed on the instructed braking intensity or pressure. Under one instruction, the driver was asked to brake *with normal braking intensity or pressure*. Under a second instruction, the driver was asked to brake with *the hardest braking intensity or pressure that they felt comfortable*. Under a third instruction, the driver was asked to brake with *hard braking intensity or pressure*. These three instruction conditions were included to provide insight into when drivers should be presented crash alert information, when drivers should not be presented crash alert information (in order to avoid in-path nuisance alerts or any tendency the driver may have to ignore an alert which does in fact signify an alarming situation), and to explore driver's interpretation of "hard braking" and "comfortable hard" braking levels. That is, the use of 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.

Drivers were discouraged from "second-guessing" and correcting their initial braking onset judgment by releasing brake pressure (or "double-pumping"), for two reasons. First, even if inaccurate, the interest here is when drivers *perceive* the need to begin braking. Second, it is anticipated that a driver response to a crash alert will typically involve either maintaining or increasing brake pressure (*rather than releasing brake pressure*) throughout the braking maneuver. Hence, it was felt the braking distance and levels observed may be representative of a driver's hard braking levels in response to a crash alert.

Test Trial Sequence

Each driver experienced three blocks of trials, each corresponding to a different braking instruction condition. The first block of trials was always conducted under the normal braking instruction, whereas the second and third block of trials were conducted under comfortable hard and hard braking instructions (with the order of these two braking instructions counterbalanced across drivers). The first block of trials served to get drivers comfortable with braking the vehicle under more normal conditions, and with the "last-second" braking instruction. Trials in which the passenger-experimenter intervened with braking were immediately repeated.

Within each block of trials, drivers experienced 15 trials. During trials 1-3, drivers braked in response to a series of three horizontally aligned traffic cones (placed perpendicular to the vehicle's path of travel). These trials served to get drivers comfortable braking with the vehicle under the last second braking instruction relevant to the block of trials. During trials 4-6, drivers experienced three Stationary Trials, with the order of the three target approach speeds (30, 45, or 60 mph) counterbalanced within a driver's testing session (across the three braking instruction conditions), as well as across drivers. During trials 7-15, drivers experienced nine Moving Trials, formed by crossing the three target speeds (30, 45, or 60 mph) with the three POV braking profile levels (-.15, -.28, or .-39 g's). During these 9 trials, drivers experienced three successive trials at each target speed (each with a different POV braking profile). The order of the three target speeds and the three POV braking profile levels were appropriately counterbalanced within a driver's testing session (across the three braking instruction conditions), as well as across drivers.

Independent Variables Examined

For Stationary Trials, the within-subjects variables analyzed were target speed (30, 45, and 60 mph) and braking instruction (normal, comfortable hard, and hard), and the between-subjects variables were age (younger, middle-aged, or older), gender (male or female), and hard braking instruction order (comfortable hard/hard or hard/comfortable hard). For Moving Trials, the within-subjects variables analyzed were target speed (30, 45, and 60 mph), POV braking profile (-.15, -.28, and -.39 g's), and braking instruction (normal, comfortable hard, and hard), and the between-subjects variables were age (younger, middle-aged, or older), gender (male or female), and hard braking instruction order (comfortable hard/hard, or hard/comfortable hard).

Dependent Measures (Or Performance Measures) Examined

Various performance measures were analyzed for Moving Trials and Stationary Trials. The variable definitions, and the point in time during the braking maneuver in which these measures were analyzed (at POV braking onset, at SV braking onset, throughout the braking, end of the braking maneuver) are shown in Table 3-1.

It should be noted that SV braking onset was <u>not</u> defined relative to the brake switch trigger point, since it was observed that some drivers had a tendency to momentarily ride the brakes during their last-second braking decision. Instead, SV braking onset was defined as the point in time in which the vehicle actually began to slow as a result of braking. Based on a manual analysis of 10% of the entire data set, SV braking onset was defined as five 30 Hz data samples (or 165 ms) prior to SV crossing the .10 g deceleration level.

The time-to-collision (or TTC) measure was examined under different assumptions about SV and POV deceleration. "*Time-to-collision*" refers to the time it would take for a collision to occur at the prevailing speeds, distances, and trajectories associated with the driver's vehicle and the closest lead vehicle (van der Horst, 1990).

In calculating the TTC during Stationary Trials, the driver's speed at SV braking onset was assumed to remain constant throughout the braking maneuver. That is, this TTC measures provides a measure of the time it would take for drivers to collide (or contact) with the lead vehicle if the drivers continued at their current (or "momentary") speed at SV braking onset.

In calculating the TTC during Moving Trials, two different cases of TTC measures were examined, which made difference assumptions about lead vehicle decelerations. Under TTC-Case 1 (identical to the Stationary Trials case above), this measure was calculated by assuming the current speeds of the driver's vehicle and the lead vehicle. That is, this TTC measures provides a measure of the time it would take for the driver to collide with the lead vehicle if the driver and the lead driver continued at their current speeds.

Under TTC-Case 2 during Moving Trials, this measure was calculated by assuming the current speeds of the driver's vehicle and the lead vehicle, as well as assuming the lead vehicle continued to decelerate at the prevailing deceleration value (i.e., at the current "constant" rate of slowing). That is, this measure provides a measure of the time it would take for the driver to collide with the lead vehicle assuming 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.

Similar underlying assumptions were made for the required deceleration measure at SV braking onset, which 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). It should be noted that in calculating both the TTC and deceleration required measures, the movement state of the lead vehicle (stationary or moving) during the "playing out" of the lead vehicle assumptions (i.e., 0 g deceleration, constant level of deceleration) was addressed.

Table 3-1 Driver Performance Measures Analyzed

Dependent Measure (Measurement Unit)	Variable Definition	Time During Braking Maneuver Which Measure Was Analyzed: At POV Braking Onset	At SV Braking Onset *	Through-out Braking	End of SV Braking
SV Speed (mph)	Speed of subject vehicle (SV)		✔		
Initial POV Speed (mph)	Speed of principal other vehicle (POV) at POV braking onset (moving trials only)	✔			
POV Speed (mph)	Speed of POV (moving trials only)		✔		
Delta Velocity (or Delta V in mph)	Difference in speeds between the SV and POV (moving trials only)		✔		
SV Deceleration (g)	Deceleration level of SV		✔		
POV Deceleration (g)	Deceleration level of POV (moving trials only)		✔		
Braking Onset Range (m)	Range (or distance) between the SV and POV at SV braking onset		✔		
Following Headway (sec)	The range between the SV and POV divided by the SV speed at POV braking onset (moving trials only)	✔			
Headway (sec)	The range between the SV and POV divided by the SV speed at SV braking onset		✔		
Time-To-Collision (or TTC in seconds)	The time it would take for the SV and POV to collide under prevailing speeds and assumed deceleration values (see text for 2 cases examined)		✔		
Required Deceleration (g)	The constant deceleration level at braking onset for the SV driver to avoid the crash, assuming the current SV and POV speeds, and that the POV vehicle continues decelerating at the prevailing deceleration value.		✔		
Actual Deceleration(g)	The constant deceleration level needed for the SV to yield the observed stopping distance			✔	
Peak Deceleration (g)	The peak (or maximum) deceleration level reached by the SV driver during the braking maneuver			✔	
Braking Distance (m)	SV stopping or braking distance			✔	
Minimum TTC (sec)	The minimum TTC value reached by the SV during the braking maneuver			✔	
Minimum Headway (sec)	The minimum time headway reached by the SV during the braking maneuver (moving trials only)			✔	
Minimum Range (m)	The minimum range between the SV and the POV reached during the braking maneuver			✔	
End Range (m)	The range between the SV and the POV when the SV has come to a full stop				✔

Note: * SV braking onset was defined relative to when the vehicle actually began slowing rather than by the brake switch trigger point.

3.3.3 Results and Discussion

Overview of Statistical Analysis Approach

A mixed factorial Analysis of Variance (ANOVA) was performed for each performance measure defined in Table 3-1. Data from Stationary Trials and Moving Trials were analyzed separately during the statistical analysis. For Stationary Trials, the within-subjects variables analyzed were target speed (30, 45, and 60 mph) and braking instruction (normal, comfortable hard, and hard), and the between-subjects variables were age (younger, middle-aged, or older), gender (male or female), and hard braking instruction order (comfortable hard/hard or hard/comfortable hard). For Moving Trials, the within-subjects variables analyzed were target speed (30, 45, and 60 mph), braking instruction (normal, comfortable hard, and hard), and POV braking profile (-.15, -.28, and -.39 g's), and the between-subjects variables were age (younger, middle-aged, or older), gender (male or female), and hard braking instruction order (comfortable hard/hard or hard/comfortable hard). This ANOVA approach was used to explore underlying relationships between the various independent variables and performance measures. Due to the exploratory nature of this research and the relatively large number of statistical tests carried out (which increases the probability of spuriously significant results, (Hays, 1981)), the criterion set for statistical significance was $p<0.01$. Statistically significant effects are shown for Stationary Trials in Table 3-2, and for Moving Trials in Table 3-3. All statistically significant results indicated in these tables at least met (and often exceeded) the adopted $p<0.01$ criterion.

It should be stressed that this analysis was considered a necessary precursor to a modeling activity aimed at predicting SV driver range at braking onset for crash alert timing purposes in planned follow-on studied examining FCW interfaces. Hence, rather than explaining and giving equal emphasis to every statistically significant effect observed (which is shown for Stationary Trials in Table 3-2, and for Moving Trials in Table 3-3), the following discussion and data presentation is more focused around the goal of determining a crash alert timing approach.

In this vein, the performance measures in Table 3-1, which will not be discussed here in any great detail, include the effects involving the braking instruction and POV braking profile variables on the following measures (all measured at SV braking onset): SV speed, SV deceleration, POV speed, and POV deceleration. In general, these effects were extremely small in magnitude and of negligible practical significance. In any case, these effects will be addressed in the subsequent modeling of these data, which will attempt to develop equations for predicting driver's braking onset range in the current study. However, one important effect involving the POV braking profile variable was actually an experimental manipulation, and indicated that the three POV braking profiles corresponded to -.15, -.28, and -.39 g's, respectively. In addition, "isolated" higher-order interaction effects, which were not generally observed across measures (i.e., Table 3-2, rows 9-10; and Table 3-3, rows 12-13 and 15-18), will not be discussed here. Once again, these effects were generally small in magnitude.

Table 3-2 Stationary Trials Data - Overview of Statistically Significant Effects (*p< .01, **p< .001, ***p< .0001)

		At Braking Onset					Throughout Braking			End of Braking
Ref. Row	**Significant Effects**	**Speed**	**Decel.**	**Range**	**TTC**	**Req. Decel.**	**Actual Decel.**	**Peak Decel.**	**Min. TTC**	**Range**
1	Age			*	*	*			*	*
2	Gender					*				
3	Order									
4	Braking Instr.		***	***	***	***	***	***	***	*
5	Speed	***	***	***	***	***	***	***	***	***
6	O x BI			*	*	***	**	***	**	*
7	A x Sp									**
8	BI x Sp			***	**		***	**	*	*
9	A x O x Sp	*								*
10	O x BI x Sp								*	

Note: For rows 6-10 above, A=Age, O=Hard Braking Instruction Order, BI=Braking Instruction, and Sp=Speed.

Table 3-3 Moving Trials Data – Overview of Statistically Significant Effects (p*< .01, ***p*< .001, ****p*< .0001)**

		At POV Braking Onset		At SV Braking Onset										Throughout Braking						End of SV Braking
Ref. Row	Significant Effects	Time Head -way	Initial POV Speed	SV Speed	SV Dec.	POV Speed	POV Dec.	Delta V	Range	Time Head -way	TTC (Case 1)	TTC (Case 2)	Req. Dec.	Actual Dec.	Peak Dec.	Min. TTC (Case 1)	Min TTC (Case 2)	Min. Head -way	Min. Range	End Range
1	Age																			
2	Gender																			
3	Order																			
4	Braking Instr.	***		***	*	***	***	***	***	***	***	***	***	***	***	***	***	***		
5	Speed	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
6	Braking Prof.			***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***
7	O x BI												*	*	***					
8	G x Sp																			
9	BI x Sp			*			**		***		*	***	*				**			
10	BI x BP			***			***		**	**	***	***	***	***	***	***	***	***	***	***
11	S x BP							*	***			***	***	***	*	**	***		***	***
12	O x BI x BP												***							
13	O x Sp x BP													***						
14	BI x Sp x BP													***					***	*
15	G x BI x BP														*					
16	A x G x Sp		*																	
17	A x G x BI x BP															*				
18	A x BI x Sp x BP																			**

Note: For rows 7-18 above, A=Age, G=Gender, O=Hard Braking Instruction Order, BI=Braking Instruction, Sp=Speed and BP=Braking Profile. During The two different cases of TTC measures examined (TTC-Case1 and TTC-Case 2) are described in the text.

Driver's Compliance to Speed Instruction and Headway Instructions

Before discussing the effects of each independent variable on the various performance measures, it is important to verify that drivers followed the experimenter instructions prior to their initiation of last-second braking. Drivers were instructed to maintain 30, 45 or 60 mph speeds. In addition, during Moving trials, drivers were instructed to follow at their normal following distance.

Results shown in Table 3-4 indicate that both the SV (and POV) were very close to target speeds during both Stationary Trials and Moving Trials. Results from Table 3-5 indicate that the average time headway observed across age groups in the current study (at POV braking onset) correspond closely to those recently observed in the manual (no adaptive cruise control) condition in the recent large-scale ACC field trials (Sayer, Fancher, Ervin, and Melford, 1997). (It should be noted that, in the current study, the effect of the age variable on this average time headway measure only reached a $p<0.10$ level of statistical significance.) This latter result provides strong evidence that drivers' time headways during Moving Trials in the current study are representative of real-world driving conditions, and were not altered by the last-second braking judgment task.

Hard Braking Instruction Order Effects

Although there were no main effects of the hard braking instruction order variable (see row 3 of Table 3-2 and Table 3-3), this variable interacted with the hard braking instruction order variable in a robust fashion during Stationary Trials (see Table 3-2, row 6), and for a few measures during Moving Trials (see Table 3-2, row 7). A representative example of this Hard Braking Instruction Order x Braking Instruction interaction is shown in Figure 3-6 for the average required deceleration measure during Stationary Trials. (This measure will be shown shortly to be a key measure for crash alert timing purposes.) This interaction indicates that during the first and third block (or set) of trials, the average required deceleration values were no different across hard braking instruction order conditions (comfortable hard/hard *versus* hard/comfortable hard). However, during the second block of trials, average required deceleration values were higher for the "hard/comfortable hard" hard braking instruction order group relative to the "comfortable hard/hard" order group. This pattern of results suggests that drivers in the latter group may have been relatively more aggressive in their third block of trials due to experiencing the "hard braking" instruction in the previous block of trials. In any case, the magnitude of this interaction effect (.02 g's) was relatively small for this measure, as well as other performance measures analyzed. Furthermore, it is interesting to note that data were more stable in the "hard" relative to "comfortable hard" braking instructions across the two hard braking instruction orders, which suggests that the driver's interpretation of "hard" braking is relatively insensitive to practice. This insensitivity to practice would seem to make data from the hard braking instruction condition a better candidate for modeling crash alert timing, particularly if drivers with a FCW-equipped vehicle are instructed that "hard" braking may be one of the appropriate responses to a crash alert. Overall, as will be shown below, the data from the comfortable hard braking instruction condition are nearly identical to that obtained in the hard braking instruction condition. This would suggest that drivers with a FCW-equipped vehicle would be capable of executing the hard braking levels observed in the current study without exceeding their "comfort zone" for hard braking. Finally, as can be seen by examining the significant interaction effects in Table 3-2 (rows 6-10) and Table 3-3 (rows 7-18), the braking instruction order variables did not generally interact across with other performance measures.

Age and Gender Effects

The only significant main effects of either age or gender occurred during Stationary Trials (see rows 1-2 of Table 3-2 and Table 3-3), when drivers experienced the highest delta velocity (and perhaps the highest perceived risk) levels. The main effects of age during Stationary Trials are shown in Table 3-6, and indicate the younger group behaved more aggressively than the middle-aged and older group, with largely no difference in behavior between the two older groups. A main effect of gender was found during Stationary Trials for only the average required deceleration measure, and indicated average required deceleration values of -.29 and -.31 g's for female and male drivers, respectively. Overall, it should be noted that main effects of age and gender are relatively small in magnitude. In addition, as can be seen by examining the significant interaction effects in Table 3-2 (rows 6-10) and Table 3-3 (rows 7-18), the age and gender variables did not generally interact with the more "kinematic-oriented" variables of speed, braking instruction, and POV Braking profile across performance measures. Hence, to the extent to which one would want to add a correction factor in crash alert timing to accommodate differences in either age and/or gender, the process is seemingly very straightforward, and the underlying relationships between the more kinematic-oriented variables (which will now be discussed) still hold.

Table 3-4 Comparison of Speed Instructions Versus Driver's Actual Speeds at the Time of Critical Braking Events

	POV Stationary Trials	POV Moving Trials	
Speed Instruction	**Average SV Speed at SV Braking Onset**	**Average SV Speed at SV Braking Onset**	**Average POV Speed at POV Braking Onset**
Maintain 30 mph	29.8	30.3	30.3
Maintain 45 mph	44.6	45.9	45.9
Maintain 60 mph	58.0	60.8	60.8

Table 3-5 Comparison of Time Headways During CAMP Moving Trials Versus UMTRI ACC Field Trials Across Age Groups

	Average Time Headways (sec)	
Age Group*	**CAMP at POV Braking Onset**	**UMTRI ACC Field Trials (Sayer et al., 1997)**
Young	1.3	1.2
Middle	1.6	1.4
Old	1.6	1.5

* The young, middle-aged and older groups in the current study were defined as 20-30, 40-51, and 60-71 years old, respectively. In the UMTRI ACC Field Trials (Sayer et al., 1997), the corresponding age groups (which are nearly identical) were 20-30, 40-50, and 60-70 years old, respectively.

Table 3-6 Effects of Age on Various Performance Measures During Stationary Trials

	At Braking Onset				
Age Group	**Ave. Range (m)**	**Ave. TTC (sec)**	**Ave. Req. Decel. (g)**	**Ave. Min TTC (sec)**	**Ave. End Range (m)**
Young	69.2	3.4	-.31	2.0	7.5
Middle	78.9	3.8	-.29	2.5	12.1
Old	79.1	3.8	-.28	2.4	11.1

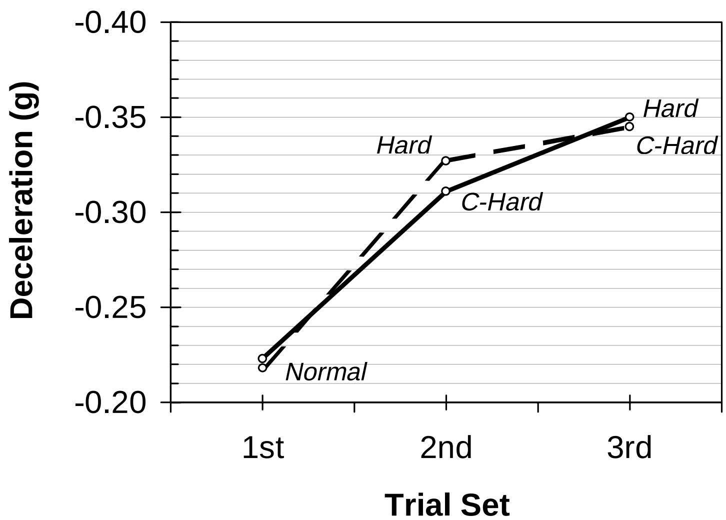


Figure 3-6 Average Required Deceleration at Braking Onset as a Function of Trial Set and Braking Instruction During Stationary Trials

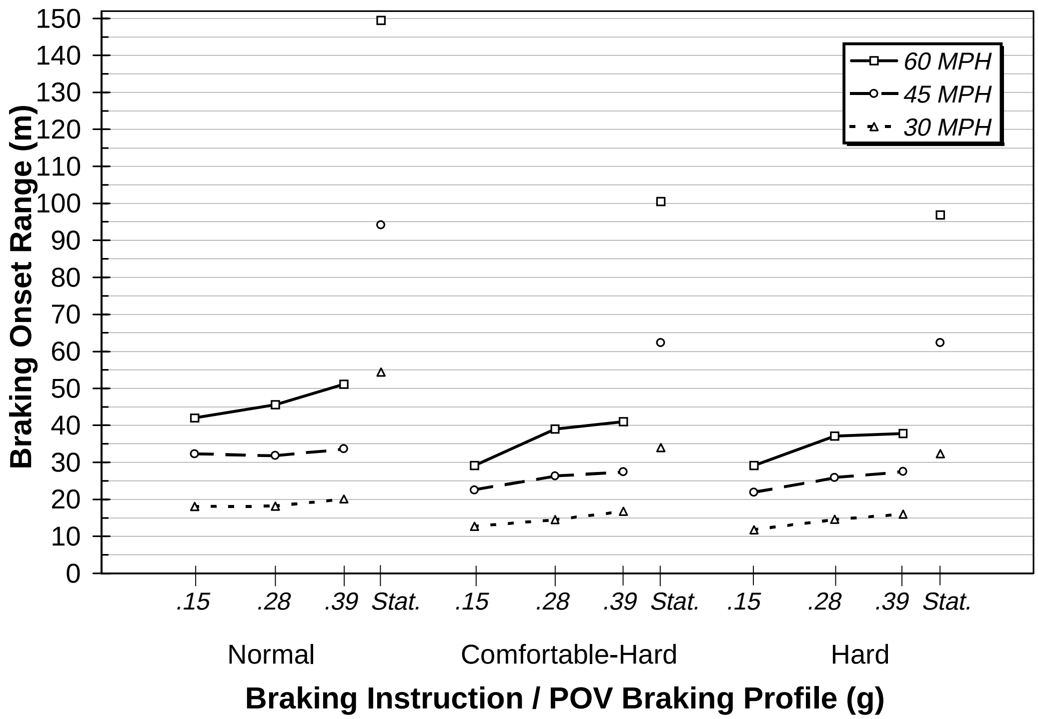


Figure 3-7 Average Range at SV Braking Onset as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

Speed, Braking Instruction and POV Braking Profile Interaction Effects: "Kinematic Figures"

Developing the "Kinematic Figure" concept

The following discussion is aimed at providing the reader a close look at the various higher-order interactions observed between the kinematic-oriented variables across performance measures. These variables play a paramount and fundamental role in determining appropriate crash alert timing. For Stationary Trials, these key kinematic-oriented variables include speed and braking instruction. For Moving Trials, these key kinematic-oriented variables include speed, braking instruction, and POV braking profile.

These kinematic-oriented variables provided robust main effects across performance measures during Stationary Trials (see Table 3-2, rows 4 and 5) and Moving Trials (see Table 3-3, rows 4-6). In addition, these key kinematic-oriented variables strongly interacted with one another. During Stationary Trials, this can be observed in the robust Speed x Braking Instruction interaction (see Table 3-2, row 8). Similarly, during Moving Trials, this can be observed in the Braking Instruction x Speed interaction (see Table 3-3, row 9), Braking Instruction x Braking

Profile interaction (see Table 3-3, row 10), and the Speed x Braking Profile interaction (see Table 3-3, row 11).

Hence, a data presentation approach which focuses on the highest-order interaction between kinematic-oriented variables provides the most powerful approach for interpreting the underlying trends of this large data set, and allowing the reader to make clean, straightforward comparisons across performance measures. For Stationary Trials, the highest-order interaction between kinematic-oriented variables is provided by the Speed x Braking Instruction (2-way) interaction. For Moving Trials, the highest-order interaction between kinematic-oriented variables is provided by the Speed x Braking Instruction x POV Braking Profile (3-way) interaction. Furthermore, in order to facilitate comparisons between data obtained during Stationary Trials and Moving Trials for a given performance measure, data from the corresponding "highest order" interactions under these two types of trials are presented on the same figure. For ease of terminology purposes, this type of figure will subsequently referred to as a "*Kinematic Figure*". For some measures, it should be noted that Stationary Trials data is not shown on the Kinematic Figure, primarily because the measure is not appropriate for these types of trials. Finally, to the extent possible, Kinematic Figures corresponding to similar performance measures are grouped together.

An example of a Kinematic Figure described above, which represents a key strategy for representing and interpreting this large data set, is shown in Figure 3-7 for the average range at SV braking onset measure. In each of these Kinematic Figures, the performance measure is shown on the vertical axis, and the various combinations of the braking instruction/POV braking profile conditions are shown on the horizontal axis. Note that for illustrative purposes, the Stationary Trials condition is represented as a POV braking profile level. Furthermore, the various lines/connecting points on the figure correspond to the three different speed conditions under each braking instruction/POV braking profile combination, with isolated non-connected points used to represent the Stationary Trials data. It should be noted that 108 drivers (with occasional outliers removed) contributed to each of the 36 data points shown on any given Kinematic Figure. In total, each Kinematic Figure represents data from approximately 3,888 last second braking judgment trials.

In interpreting these Kinematic Figures, it is useful to point out that data from the normal braking condition is less aggressive than that obtained from the hard and comfortably hard braking conditions. Also, the data from the comfortable hard braking instruction condition is nearly identical to that obtained in the hard braking instruction condition. (As was mentioned earlier, this latter finding would suggest that drivers with a FCW-equipped vehicle would be capable of executing the observed braking levels in the current study without exceeding their "comfort zone" for hard braking.) Hence, in analyzing these Kinematic Figures with an eye toward thinking about crash alert timing, the reader may find it advantageous to focus on data from the hard braking instruction condition (the rightmost third of the figure), which provides additional rationale for the "Kinematic Figure" approach. Indeed, data from the hard braking instruction condition will be the focus of much of the following discussion. The importance of data from the normal braking instruction condition and its relevance to driver annoyance (i.e., in-path nuisance alerts) will be primarily discussed later when examining percentile data. Next, a brief discussion will be provided of each of the Kinematic Figures corresponding to various performance measures.

Delta V

The Kinematic Figure corresponding to the average difference in velocities (or delta V's) between the SV and POV at SV braking onset is shown in Figure 3-8. Although the data from Stationary Trials is not shown in this figure (since it would triple the size of the vertical scale, and diminish the readers ability to see the pattern of results during Moving Trials), the reader should know that the delta velocities during Stationary Trials simply correspond to the driver's speeds at SV braking onset. These latter speeds corresponded very closely to drivers' instructed speeds (see Table 3-4). Under the hard braking instruction conditions during Moving Trials, the average delta velocities ranged from 8-16 mph. As can be seen in Figure 3-8, overall, the delta V's increased as the (instructed) speeds increased and as the lead vehicle (POV) braked harder. This pattern of results is generally true across measures, many of which are highly correlated. It is also interesting to note that the 85th percentile delta V's ranged from 13-26 mph across the hard braking instruction conditions.

Peak Decelerations

The Kinematic Figure corresponding to the average peak deceleration of the SV throughout the braking maneuver is shown in Figure 3-9. Across all hard braking instruction conditions, the average peak deceleration values ranged between -.75 and -.90 g's. During Stationary Trials, the average peak decelerations remained relatively constant across approach speeds. In contrast, during Moving Trials, the average peak deceleration values increased as speeds increased from 30 mph to the two higher speeds (45 mph and 60 mph), and increased as the POV braked harder.

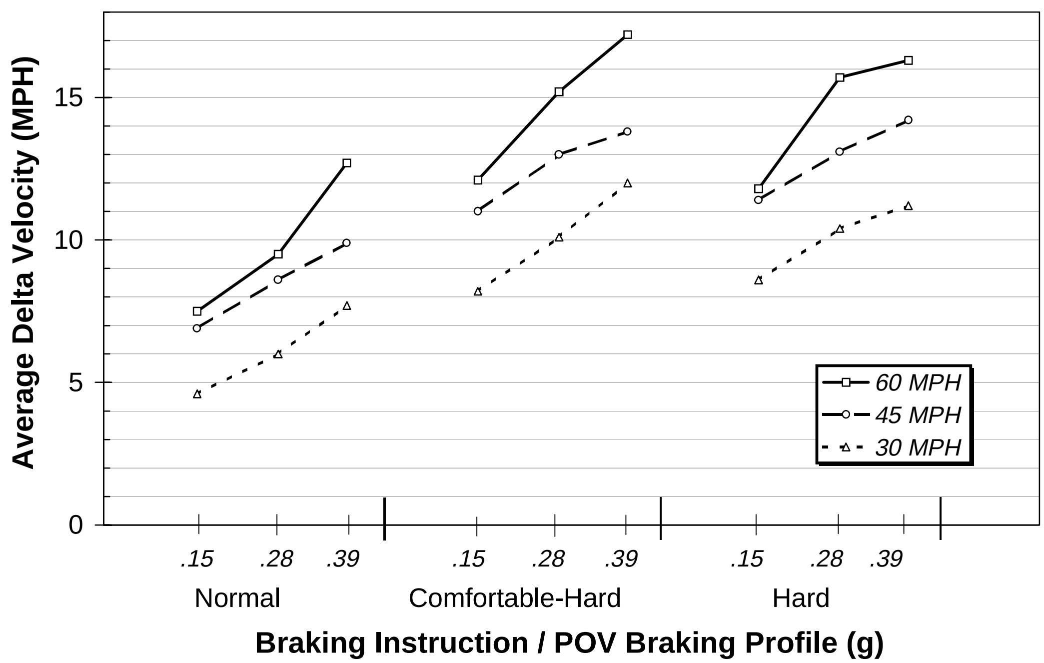


Figure 3-8 Average Differences in Velocities (Delta V) Between the SV and POV at SV Braking Onset During Moving Trials as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

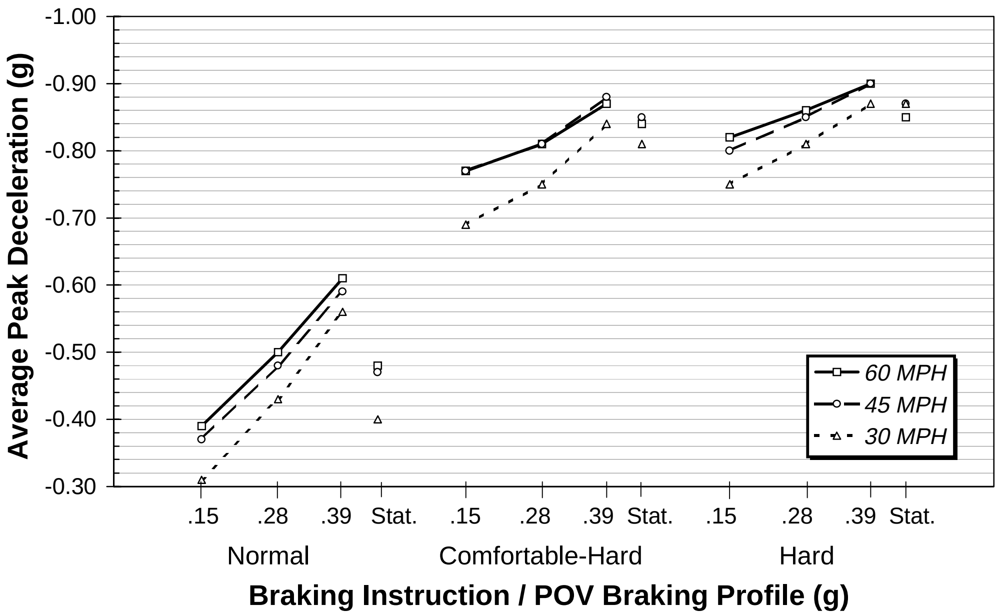


Figure 3-9 Average Peak Deceleration of the SV Throughout Braking as a Function of Braking Instruction, POV Profile, and Speed Condition

Range at Braking Onset / Exploring Sensor Range Requirements

The Kinematic Figure corresponding to the average range between the SV and POV at SV braking onset is shown in Figure 3-7. This figure indicates that, overall, the average range at SV braking onset increased as speeds increased and as the lead vehicle (POV) braked harder. This figure clearly illustrates that in terms of determining requirements for FCW sensor range, situations corresponding to the Stationary Trials condition (e.g., a parked vehicle) will demand substantially longer driver warning distances than situations corresponding to Moving Trials.

Figure 3-10 examines the Stationary Trials data in terms of exploring potential requirements for driver warning distances (and hence, FCW sensor ranges). In this figure, a 1.7 second travel distance (based on observed speeds in the three different speed conditions) is added to three following measures; average stopping distance, average range between the SV and POV at SV braking onset, and 90th percentile stopping distances. (These latter stopping distances can be viewed of as long, or conservative.) The 1.7 seconds value is based on an assumed 1.5 second percentile P-RT, and an additional 0.2 second system delay time (which included the time it takes for the vehicle to begin slowing after the brakes are applied). The assumed driver P-RT time corresponds to an 85th-95th percentile driver perception-response time value (Olson, 1996), which is a percentile range commonly used in traffic engineering. (The reader can easily explore other assumed P-RT values by converting the assumed driver P-RT to a travel distance across the three speeds, and adding this distance to the measures provided in Figure 3-10.)

As can be seen in Figure 3-10, the 100 meters of “sensor knowledge” accommodates the proposed potential driver warning distances for avoiding a crash in the 30 and 45 mph speed condition (for 90% of drivers in the 45 mph condition), but falls short in the 60 mph condition. It should be stressed that substantial collision mitigation would still be possible in this latter speed condition. It should also be noted that the above conclusions assume that drivers will at least match the observed hard braking levels in the current study under real-world conditions in response to a crash alert, and that the road surface coefficient of friction can support the hard braking levels observed in the current study (which may not be true under wet, snowy, or icy road surface conditions).

Braking Distance

Although this measure was not statistically analyzed (since it is redundant with the average deceleration measure), the Kinematic Figures corresponding to SV braking distance is shown in Figure 3-11. As can be seen in this figure, overall, the average braking distances increased as speeds increased and decreased as the lead vehicle braked harder. It is also interesting to note that the across the three speed conditions under both comfortable hard and hard braking instruction conditions, braking distances found during Stationary Trials correspond closely to those found during Moving Trials in the -.28 g POV braking profile condition .

Minimum Range / End Range

The Kinematic Figures corresponding to the average minimum range throughout braking and the average end range are shown in Figure 12 and Figure 13, respectively. Note that these two variables are equivalent during Stationary Trials, and that these data are redundantly displayed in both of these two Kinematic Figures. During Moving trials, these two variables are not necessarily identical, since the minimum range can occur during the actual braking maneuver. Both Figure 12 and Figure 13 indicate that, overall, both the average minimum range and average end range increased as speeds increased, and decreased as the lead vehicle braked harder. For the hard braking instruction condition during Stationary Trials, the average minimum range (or equivalently, average end range) shown in Figure 13 increased approximately 1-3 mid-size car lengths in a fairly linear fashion as target speeds increased from 30-60 mph. The definition used here of a mid-size car length is 5.1 m, which corresponds to the length of a Chevrolet Lumina or Ford Taurus. Interestingly, this same pattern of results was true for the minimum range measure during Moving Trials for the hardest POV braking profile condition (-.39 g). Overall, these results would appear to suggest that a driver’s preferred “buffer zone” increased with driver speed.

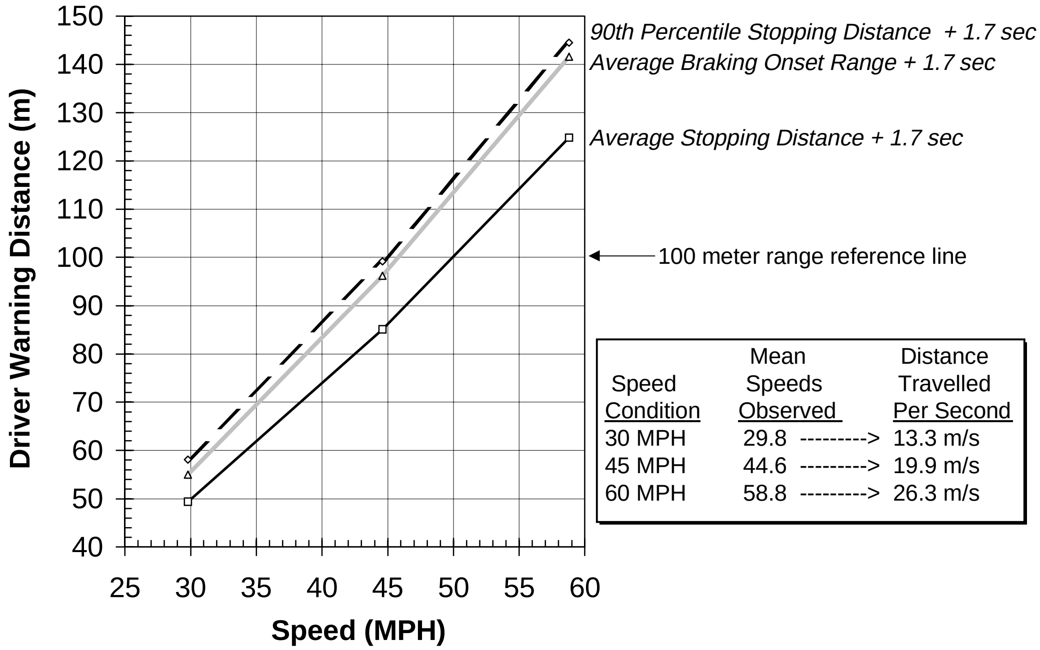


Figure 3-10 Potential "Driver Warning" Distances Based on Adding 1.7 Seconds Travel Distance to the Following Measures in the Hard Braking/Stationary Trials Conditions: Ave. Braking Onset Range, Ave. Stopping Distance, and the 90th Percentile Stopping Distance

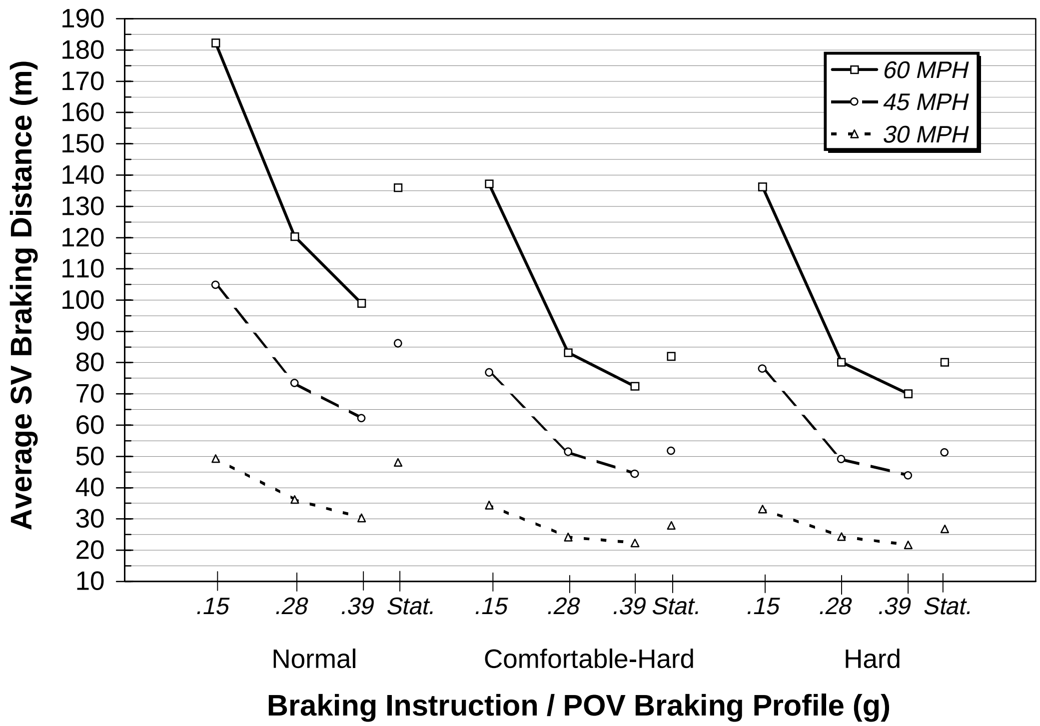


Figure 3-11 Average SV Braking Distance as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

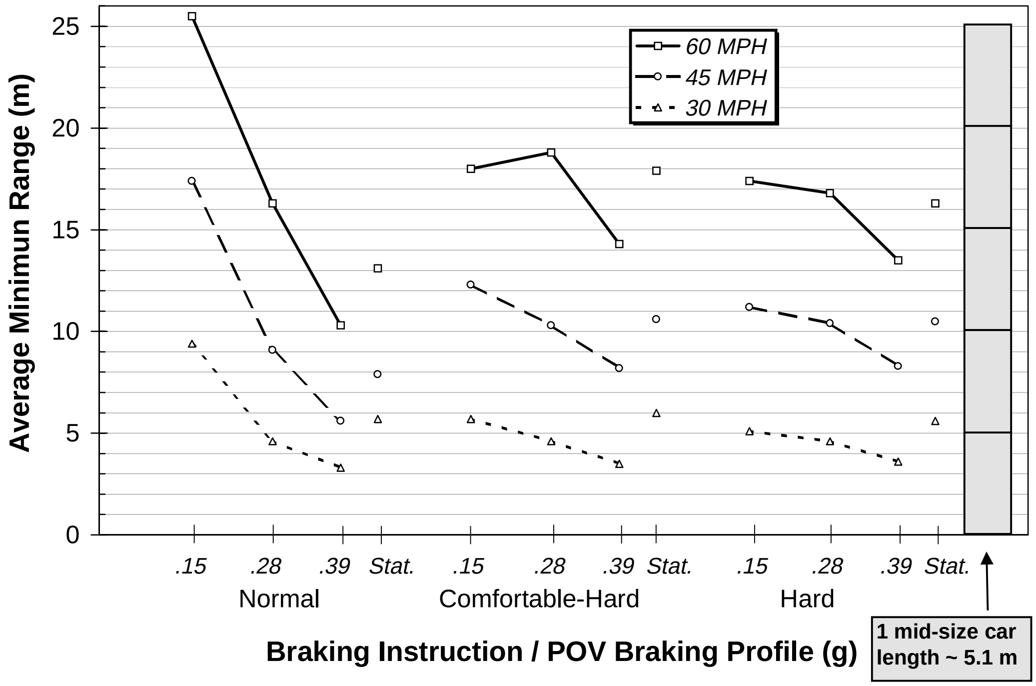


Figure 3-12 Average Minimum Range Throughout Braking as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

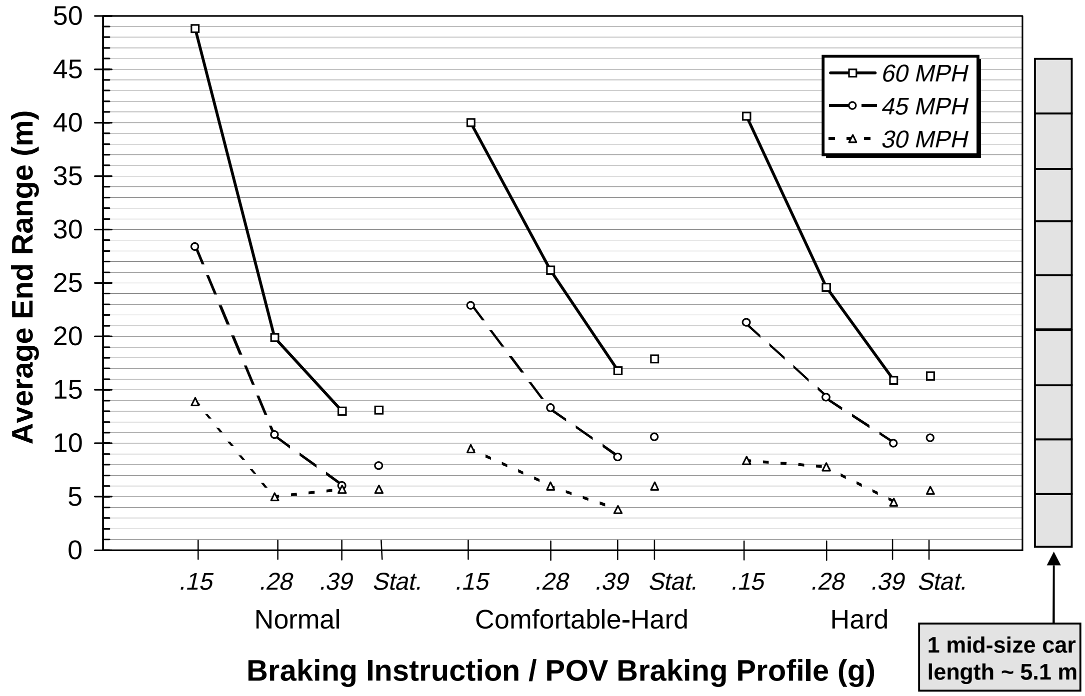


Figure 3-13 Average End Range as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

However, the interpretation of these minimum range and end range data are not straightforward, since (as discussed above in the “Procedure and Design” section) drivers were discouraged from “second-guessing” and correcting their initial braking onset judgment by releasing brake pressure (or “double-pumping”). Hence, this constraint *may* have resulted in higher (more conservative) end ranges and/or higher minimum ranges than may have been obtained if drivers were given the opportunity to release pressure off the brakes during the brake maneuver. This hypothesis will be further tested in the two follow-up closed course studies, which will not constrain the driver’s braking behavior in this manner, and will also include unexpected braking events.

Actual Deceleration and Required Deceleration

Before discussing the results from the actual deceleration and required deceleration measures, which will be argued to be the most important variables examined here for developing a FCW crash alert timing approach, it is important to elaborate on the definitions of these variables provided earlier in Table 3-1. Figure 3-14 provides an illustration of the definition of these measures for the Stationary Trials condition. Referring to Figure 3-14, the reader is to imagine the vehicle shown on the left is approaching the parked vehicle shown to the far right, and then begins braking, and eventually comes to a stop. The top illustration depicts the case where the driver’s braking distance enables the driver to avoid colliding with the lead vehicle by a few car lengths. The braking distance observed could than be re-expressed as the constant (or fixed) deceleration level needed to yield the actual (observed) stopping distance, defined as the *actual deceleration* measure. Now imagine replaying this same exact sequence of events, except the driver comes to a stop right at the front bumper of the lead vehicle. The “hypothetical” braking distance observed can than be re-expressed as the constant (or fixed) deceleration level required for the driver to avoid the crash at braking onset, defined as the *required deceleration* measure. Note that assuming the driver avoids the crash, the actual deceleration value is always greater than the required deceleration value. However, the exact relationship between the actual and required deceleration measures is in no way predetermined or inherently straightforward. That is, the relationship between these measures may be different across drivers, as well as for any given driver across different vehicle-to-vehicle kinematic conditions.

Data from both the actual and required deceleration measures under Stationary Trials conditions is shown in Figure 3-15. For both measures, this figure reveals only small differences between the comfortable hard and hard braking conditions, and a consistent (approximately .07 g) difference or “tight coupling” between the actual and required measures. Furthermore, both measures increased as the driver’s speed increased (i.e., people braked harder at higher speeds). The Kinematic Figures corresponding to the actual and required deceleration measures (which also include the Stationary Trials data shown in Figure 3-15) are shown in Figure 3-16 and Figure 3-17, respectively. As was found during Stationary Trials, during Moving Trials, these two figures reveal only small differences between the comfortable hard and hard braking conditions, and a consistent difference or “tight coupling” between the actual and required deceleration measures (this effects can be better observed by overlaying transparencies of each of these two figures). Furthermore, both measures increased as the lead vehicle braked harder. For two hardest POV braking profile conditions (-.28 and -.39 g’s) during Moving Trials, both the actual and required deceleration measures increased as the driver’s speed increased (i.e., people braked harder at higher speeds), particularly at the hardest POV braking profile condition (-.39 g's). However, for the least aggressive POV braking profile condition (-.15 g's), both the actual and required deceleration measures remained stable across driver speeds.

Overall, and in sharp contrast to commonly proposed crash alert timing approaches, these results suggest that it may be advantageous to vary the assumed driver deceleration value for crash alert timing as a function of driver speed and lead vehicle deceleration. Across the entire range of experimental conditions tested under the hard braking instruction condition, the average required deceleration values ranged from -.22 to -.45 g's (as can be seen in Figure 3-17). This range can be compared to the driver deceleration values assumed in the early phase of CAMP program (prior to Human Factors testing), which assumed fixed -.3 and -.5 g values for the driver's response to cautionary and imminent crash alerts, respectively.

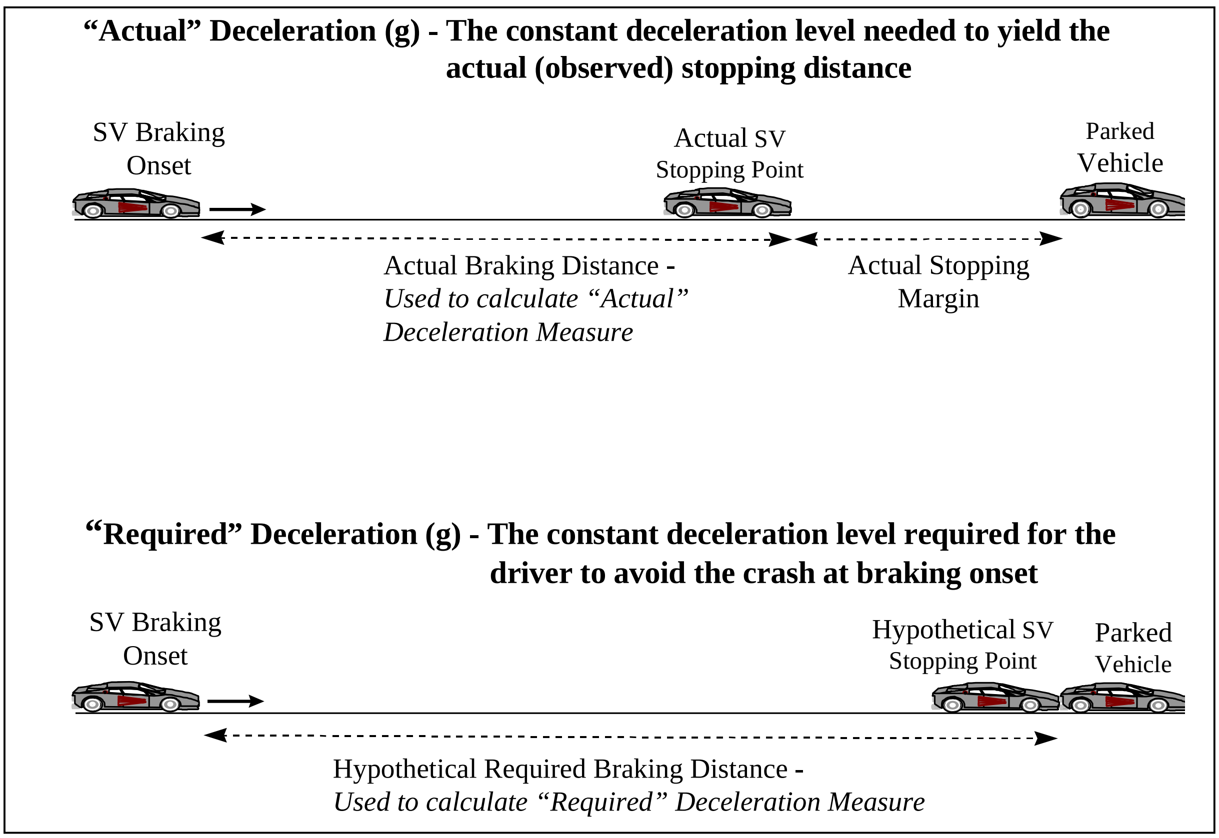


Figure 3-14 Definition of "Actual" Deceleration and "Required" Deceleration Measures (Illustrated for Case Where Lead Vehicle is Stationary or Parked)

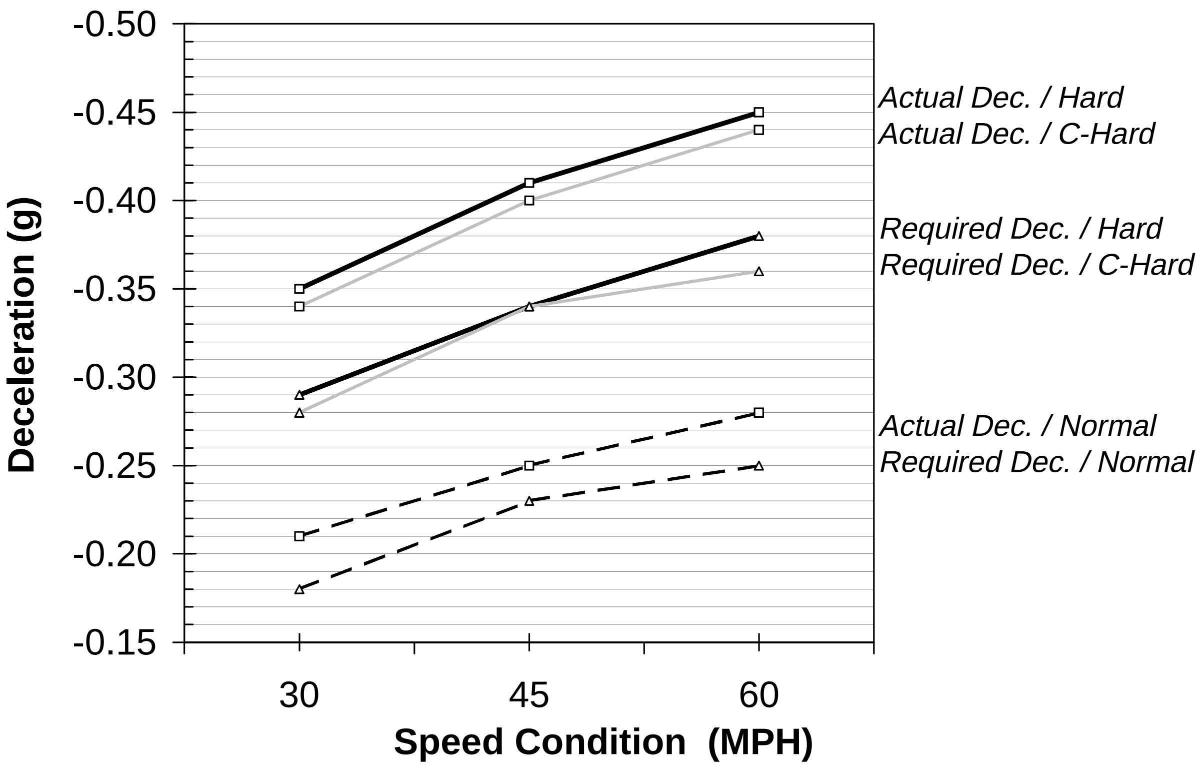


Figure 3-15 Average "Required" Deceleration and Average "Actual" Deceleration Values as a Function of Speed Condition and Braking Instruction for the Stationary Trials

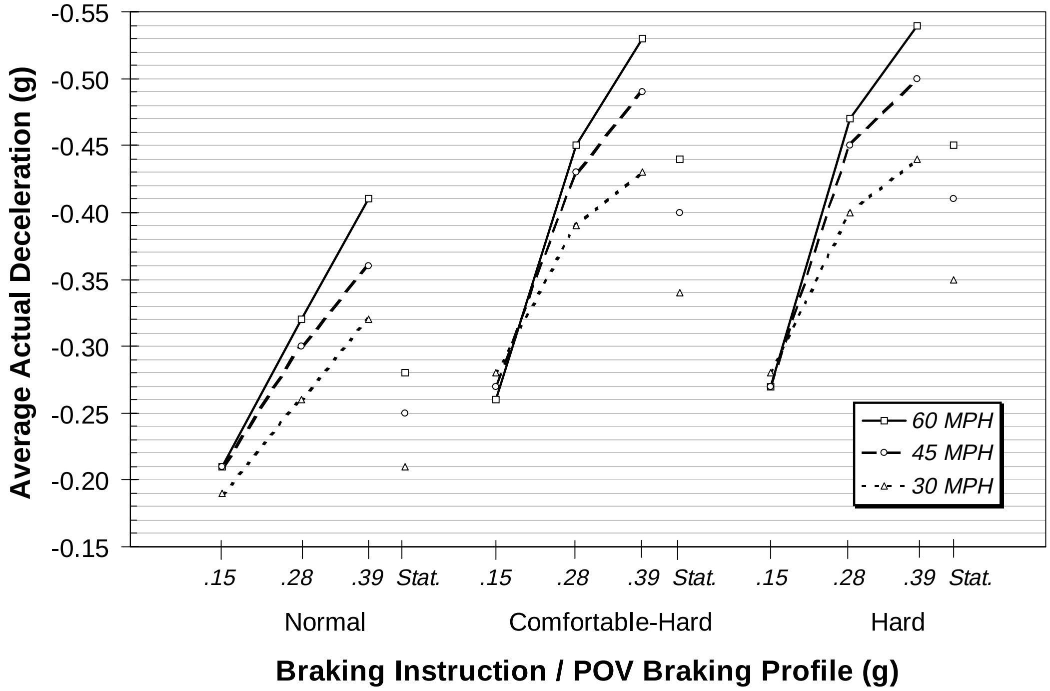


Figure 3-16 Average "Actual" Deceleration of SV as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

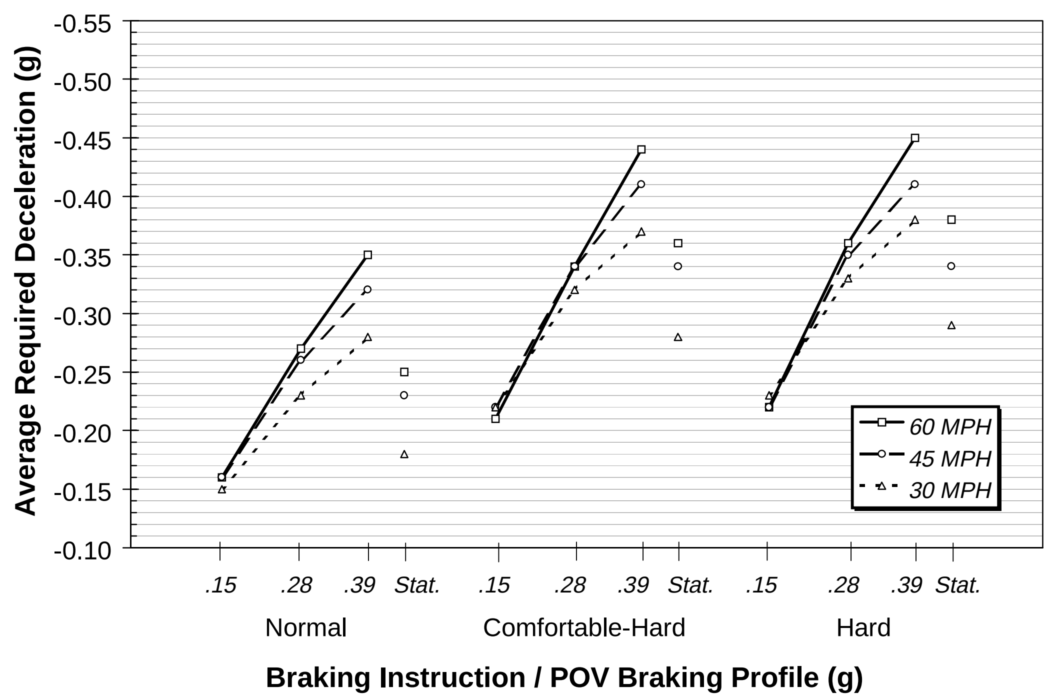


Figure 3-17 Average "Required Deceleration of SV at SV Braking Onset as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

Actual and Required Deceleration: Promising Measures for Developing a Crash Alert Timing Approach

As was touched upon earlier, the actual deceleration and required deceleration measures appear to be the most important variables of all those examined here for developing a crash alert timing approach, for two primary reasons.

First, the required deceleration measure appears to be tightly coupled to a fundamental kinematic variable, braking or stopping distance (re-expressed here in terms of an actual deceleration measure). The time-based measures (TTC or headway), which will be discussed soon, do not provide a direct linkage to a fundamental kinematic variable.

Second, a “stability” analysis of performance measures across experimental conditions suggests that the required deceleration measure remain more stable (in terms of either central tendency or data spread measures) than either the actual deceleration measure or any of the time-based measures examined at SV Braking Onset (i.e., TTC-Case 1, TTC-Case 2, time headway). To the extent that a measure is stable across experimental conditions for a given driver, and that measure’s stability is consistent across drivers, the measure offers two important advantages. First, the measure may come closer to matching the underlying criterion drivers use for deciding when to brake and how hard to brake. Second, the measure may eliminate (or at least mitigate) the need for a crash alert criterion control, which is a desirable feature from a production implementation and a simplicity/ease of use perspective.

This “stability” analysis is shown in Table 3-7 and Table 3-8 for Stationary Trials and Moving Trials, respectively, and involves calculating *coefficients of variation* (*COV*). The COV is defined for a given measure as the standard deviation divided by the mean (standard deviation/mean). This measure allows the distinct advantage of comparing across measures on the same “normalized” scale. Each table entry of Table 3-7 and Table 3-8 is based on 108 separate COV measures, with each driver contributing a single COV measure based on all the trials experienced under comfortable hard and hard braking conditions (i.e., 6 trials under Stationary Trials conditions and 18 trials Moving Trials conditions).

For each COV measure shown in the left-hand column of Table 3-7 and Table 3-8, a measure’s stability is reflected by low values. The measures corresponding to the central tendency of the COV (i.e., average, median) provide a measure of the extent to which the measure remains stable across experimental conditions for a given driver. During Stationary Trials, paired t-tests revealed significantly lower mean COV values for the required deceleration measure relative the TTC-Case 1 measure ($p < 0.0001$), with no difference found between the actual and required deceleration measure. During Moving Trials, paired t-tests revealed significantly lower mean COV values for the required deceleration measure relative to the TTC-Case 1 measure ($p < 0.0001$), with no difference found between the required deceleration measure and the actual deceleration, TTC-Case 2, and time headway measures.

The measures in the left-hand column of Table 3-7 and Table 3-8 corresponding to the variation or spread of the COV measure (i.e., standard deviation, minimum value, and maximum value) provide a measure of the extent to which a measure's stability across experimental conditions for a given driver is consistent across drivers. Hence, in this case, a measure's stability is reflected by low COV standard deviations, low COV minimum values, and low COV maximum values. During Stationary Trials, overall, the required deceleration measure shows lower values across these measures of COV variability relative to the actual deceleration and TTC-Case 1 measures. During Moving Trials, overall, the required deceleration measure shows lower values across these measures of COV variability relative to the actual deceleration and the time-based measures examined at SV Braking Onset (i.e., TTC-Case 1, TTC-Case 2, time headway). It is worthwhile noting that the time headway measure appears surprisingly stable relative to the TTC measures.

Hence, in addition to the "tight coupling" observed between the required deceleration measure and the actual deceleration measure, this COV "stability" analysis provides further supports further for exploring the required deceleration measure for crash alert timing purposes. Another fruitful avenue for exploring the required deceleration measure for crash alert timing purposes is to examine percentile values, which is a common practice in traffic engineering (e.g., using 85th-95th percentile values for design purposes). Table 3-9 and Table 3-10 provides the data which is the basis for an argument that the 50th percentile required deceleration value during hard braking may be a well-founded assumption for the assumed driver deceleration in response to a crash alert. In making this argument, it is best to start by examining a "nominal" experimental condition in the study, which is during Moving Trials where the instructed speed was 45 mph and the lead vehicle braked at -.28 g's. Percentile data for this nominal condition is shown in Figure 3-18. The arguments made below for this specific experimental condition hold equally well for the remaining experimental conditions, which will be discussed shortly (and is supported by data from Table 3-9 and Table 3-10).

The left-most percentile curve in Figure 3-18 represents data for the required deceleration measure under the normal braking instruction condition. As can be seen by the vertical dotted line on this figure, more than 96% of all (108) drivers exhibited required deceleration values of approximately -.35 g's or *less*. Put in another way, only 4% of drivers exhibited required deceleration values of approximately -.35 g values or *more* in the normal braking instruction condition.

The middle percentile curve in Figure 3-18 represents data (once again) for the required deceleration measure, but this time under the hard braking instruction condition. As can be seen by the vertical dotted line on this figure, the 50th percentile required deceleration value under the hard braking instruction is approximately -.35 g. Hence, coupling this curve with the left-most percentile curve suggests that assuming the 50th percentile required deceleration value observed during hard braking for crash alert timing (i.e., the assumed driver deceleration in response to a crash alert) would be unlikely to annoy drivers doing "normal" braking (via an in-path nuisance alert). This is particularly true if the assumption is made that the observed required deceleration values during the normal braking instruction condition are more "aggressive" than corresponding values during normal "real-world" braking, largely because the "normal" braking in this study was performed in the context of a last-second braking instruction.

Table 3-7 Coefficients of Variation (COV) Within-Subjects for Select Performance Measures Relevant for Crash Alert Timing Purposes During *Stationary Trials* (COV=Standard Deviation/Average)

	Performance Measure at SV Braking Onset		
Coefficient of Variation Measure	**Required Deceleration (g)**	**Actual Deceleration (g)**	**TTC-Case 1 (sec)**
Average	0.16	0.17	0.22
Median	0.16	0.16	0.22
Standard Deviation	0.05	0.07	0.06
Minimum Value	0.06	0.07	0.10
Maximum Value	0.30	0.70	0.35

Note: Each table entry above is based on 108 separate COV measures (one per driver), with each driver contributing a single COV measure based on 6 Stationary Trials. These 6 trials correspond to the 3 "comfortable hard" braking instruction trials and the 3 "hard" braking instruction trials, where the 3 trials in each of braking instruction condition correspond to the 3 speed condition levels.

Table 3-8 Coefficients of Variation (COV) Within-Subjects for Select Performance Measures Relevant for Crash-Alert Timing Purposes During *Moving Trials* (COV = Standard Deviation/Average)

	Performance Measure at SV Braking Onset				
Coefficient of Variation Measure	**Required Deceleration (g)**	**Actual Deceleration (g)**	**TTC-Case 1 (sec)**	**TTC-Case 2 (sec)**	**Time Headway (sec)**
Average	0.29	0.29	0.35	0.28	0.28
Median	0.29	0.29	0.33	0.28	0.27
Standard Deviation	0.04	0.08	0.11	0.06	0.07
Minimum Value	0.16	0.16	0.18	0.17	0.13
Maximum Value	0.41	0.74	1.00	0.52	0.48

Note: Each table entry above is based on 108 separate COV measures (one per driver), with each driver contributing a single COV measure based on 18 Moving Trials. . These 18 trials correspond to the 9 "comfortable hard" braking instruction trials and the 9 "hard" braking instruction trials, where the 9 trials in each of braking instruction condition are formed by the crossing of the 3 speed condition levels by the 3 POV Braking Profile levels.

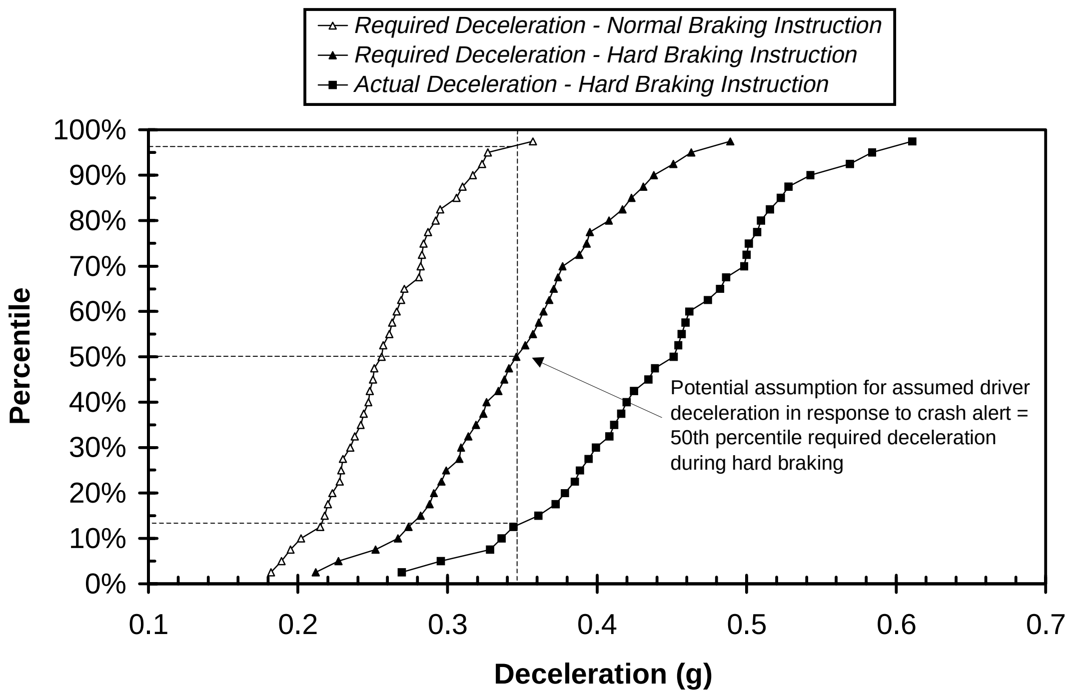


Figure 3-18 Percentile Values for the "Required" and "Actual" Deceleration Measures During Moving Trials for the 45 mph/-0.28 g POV Braking Profile Condition

Table 3-9 Exploring the Utility of Deceleration-Based Measures for Crash-Alert Timing Purposes with *Stationary Trials* Data

			Speed Condition		
Braking Instr. Cond.	**Deceleration Measure**	**%tile**	**30 mph**	**45 mph**	**60 mph**
Normal	Required Deceleration	95th	-.27	-.32	-.35
Hard	Required Deceleration	50th	-.29 (-.29)	-.34 (-.34)	-.38 (-.38)
Hard	Actual Deceleration	15th	-.28	-.34	-.36

Note: Values in parentheses indicate corresponding mean values. Also, it should be stressed that Study 1 normal braking can be considered on the aggressive side of normal braking.

Table 3-10 Exploring the Utility of Deceleration-Based Measures for Crash Alert Timing Purposes with *Moving Trials* Data

			Speed Condition (mph) / POV Braking Profile Condition (g)								
Braking Instr. Cond.	**Deceleration Measure**	**%tile**	**30 / -.15**	**30 / -.28**	**30 / -.39**	**45 / -.15**	**45 / -.28**	**45 / -.39**	**60 / -.15**	**60 / -.28**	**60 / -.39**
Normal	Required Deceleration	95th	-.20	-.30	-.37	-.20	-.33	-.42	-.21	-.34	-.45
Hard	Required Deceleration	50th	-.23 *(-.23)*	-.33 *(-.33)*	-.38 *(-.38)*	-.22 *(-.22)*	-.35 *(-.35)*	-.41 *(-.41)*	-.21 *(-.22)*	-.36 *(-.36)*	-.45 *(-.45)*
Hard	Actual Deceleration	15th	-.22	-.31	-.36	-.22	-.36	-.41	-.21	-.39	-.45

Note: Values in parentheses indicate corresponding mean values. Also, it should be stressed that Study 1 normal braking can be considered on the aggressive side of normal braking.

The next important question to ask is whether drivers would be capable of braking to avoid the crash if the 50th percentile required deceleration value observed during hard braking was used as the assumed driver deceleration in response to a crash alert. The right-most percentile data curve in Figure 3-18 represents for the actual deceleration values under the hard braking instruction. As can be seen by the vertical dotted line on this figure which passes through the 50th percentile required deceleration values data under the hard braking instruction, the actual deceleration values for 13% of drivers fall to the left of this line, which suggest that for these drivers the 50th percentile required deceleration value (during hard braking) is too aggressive for allowing them to avoid the crash (although collision mitigation may occur). On the other hand, for approximately 87% of the drivers, the 50th percentile required deceleration value during hard braking accommodates the actual deceleration values observed during hard braking. If it is assumed that drivers will in fact brake harder (if required) under real-world condition than observed in the current study, than the 15% of the drivers not accommodated by the 50th percentile required deceleration value during hard braking would be substantially reduced or eliminated. This would in effect move the rightmost percentile curve in Figure 3-18 farther to the right.

Corresponding data for the remaining experimental conditions are shown in table form in Table 3-9 for Stationary Trials and Table 3-10 for Moving Trials. (These two tables also reinforce the point made above that the required deceleration measures are a function of both driver speed and lead vehicle deceleration.) For each experimental condition (including the nominal condition discussed at length above), three percentile values are provided:

- The *95th* percentile *required deceleration* value under *normal braking* conditions.
- The *50th* percentile *required deceleration* value under *hard braking* conditions.
- The *15th* percentile *actual deceleration* value under *hard braking* conditions.

The pattern of results in Table 3-9 for Stationary Trials and in Table 3-10 for Moving Trials provide strong evidence that the arguments made above for nominal 45 mph / -.28 g condition during Moving Trials (shown in middle part of Table 3-9) hold equally well for the remaining experimental conditions.

First, across experimental conditions during both Stationary Trials and Moving Trials, the 95th percentile required deceleration value observed under normal braking instruction conditions virtually never exceeds (with one exception) the 50th percentile required deceleration value observed under hard braking instruction conditions. Assuming a 50th percentile required deceleration value during hard braking for crash alert timing (i.e., the assumed driver deceleration in response to a crash alert), would be unlikely to annoy drivers doing “normal” braking particularly if the assumption is made that the required deceleration values during the normal braking instruction observed in this study are more aggressive than corresponding values during normal real-world driving.

Second, across experimental conditions during both Stationary Trials and Moving Trials, the 50th percentile required deceleration value observed under hard braking instruction conditions is remarkably close to the 15th percentile actual deceleration value observed under hard braking conditions. Hence, for approximately 85% of the drivers, the 50th percentile required deceleration value during hard braking accommodates the actual deceleration values observed during the hard braking instruction condition. If it is assumed that drivers will in fact brake harder (if required) under real-world conditions than observed in the current study, than the remaining approximately 15% of the drivers not accommodated by this approach may be substantially reduced or eliminated.

Hence, overall, assuming the 50th percentile required deceleration value during the hard braking condition for the assumed driver deceleration in response to a crash alert appears promising. First, it appears that only a relatively small percentage of drivers (less than 5%) would find this assumed SV driver deceleration response to be not aggressive enough. However, if one assumes the normal braking levels observed here are more aggressive than in the real world, this small percentage of drivers may be reduced or eliminated. Second, it appears that only a relatively small percentage of drivers (less than 15%) would find this assumed SV driver deceleration value too aggressive. (It should be noted that these drivers may experience some level of collision mitigation). However, if one assumes that drivers could in fact brake harder (if required) under real-world conditions relative to those here, this relatively small percentage of drivers may be reduced or eliminated. This assumption will be further tested in two follow-up closed course studies, which will also include unexpected braking events.

In any case, the 50th percentile required deceleration value observed during hard braking appears to provides a solid anchor and foundation for assumptions surrounding the assumed driver deceleration in response to a crash alert. More generally, in terms of estimating driver's maximum braking capabilities, it is interesting to note that the highest (i.e., most aggressive) 15th percentile actual deceleration value across experimental conditions was -.45 g's (see bottom rows of Table 3-9 and Table 3-10). This "highest" value occurred during Moving Trials in the 60 mph /-.39 POV braking profile condition.

Time-Based (Headway and TTC) Measures

For the reasons discussed in detail above, the time-based measures examined at SV Braking Onset (TTC-Case 1, TTC-Case 2, and time headway) do not appear as promising as deceleration-based measures for developing FCW crash alert timing. Briefly, these reasons included the lack of a direct linkage of time-based measures to a fundamental kinematic variable (e.g., braking distance), and the finding (via a "stability" covariance analysis) that the required deceleration levels (or values) remain more stable than any of the time-based measures examined at SV braking onset (i.e., TTC-Case 1, TTC-Case 2, time headway).

However, given the large amount of previous work examining these time-based measures (see van der Horst (1990) for a review of this work), the interested reader is provided Kinematic Figures for each of the time-based measures defined in Table 3-1 in Figure 3-19 through Figure 3-24. The reader should note that for Stationary Trials, the time-based measures at SV braking onset (i.e., time headway, TTC-Case 1, and TTC-Case 2.) are equivalent, and redundantly provided on each of these Kinematic Figures for comparative purposes. It should also be noted that the minimum

TTC values observed during the braking maneuver have been previously interpreted as a measure of the imminent danger of a collision during the braking maneuver (van der Horst, 1990).

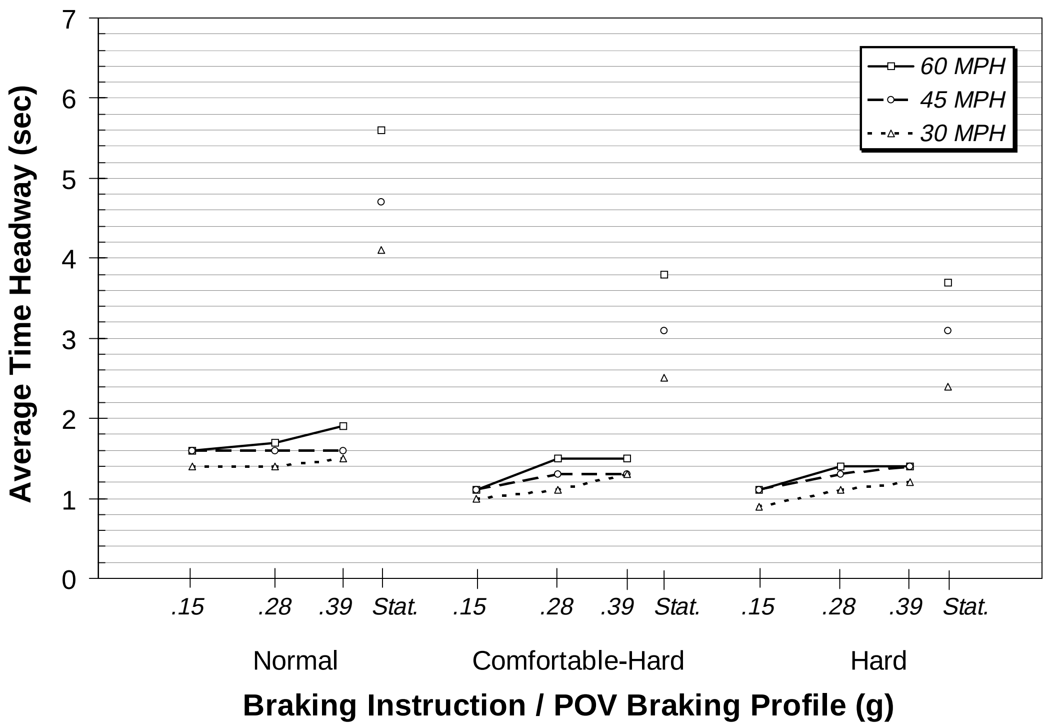


Figure 3-19 Average Time Headway at SV Braking Onset as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

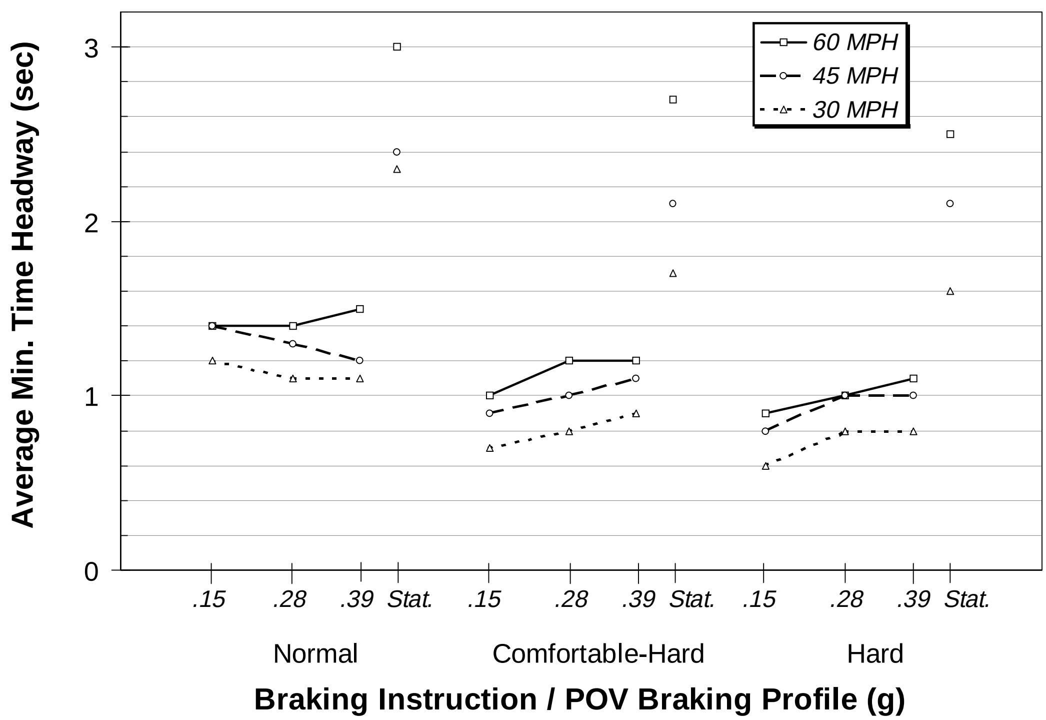


Figure 3-20 Average Minimum Time Headway Throughout Braking as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

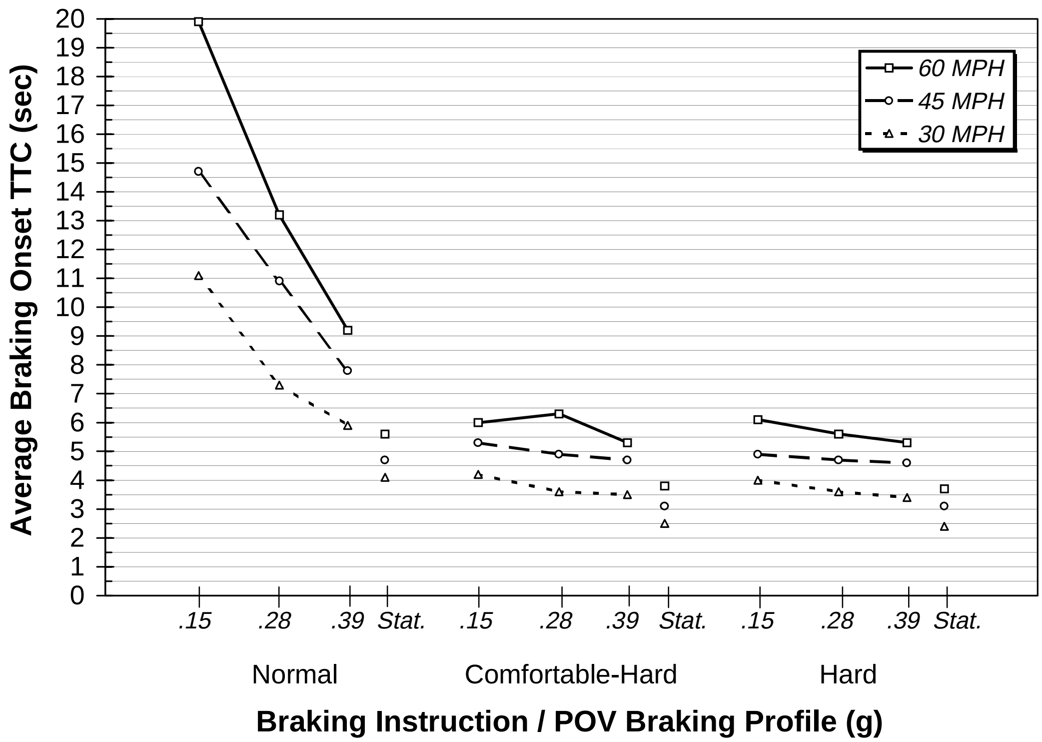


Figure 3-21 Average TTC (Case 1) at SV Braking Onset as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

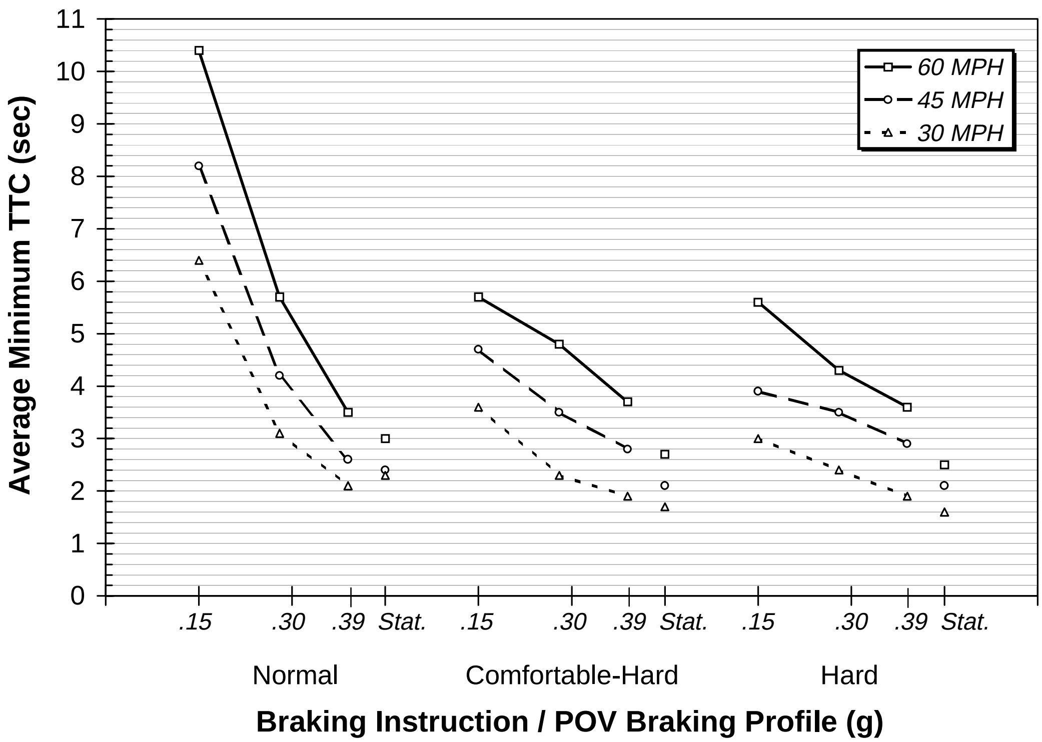


Figure 3-22 Average Minimum TTC (Case 1) Throughout Braking as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

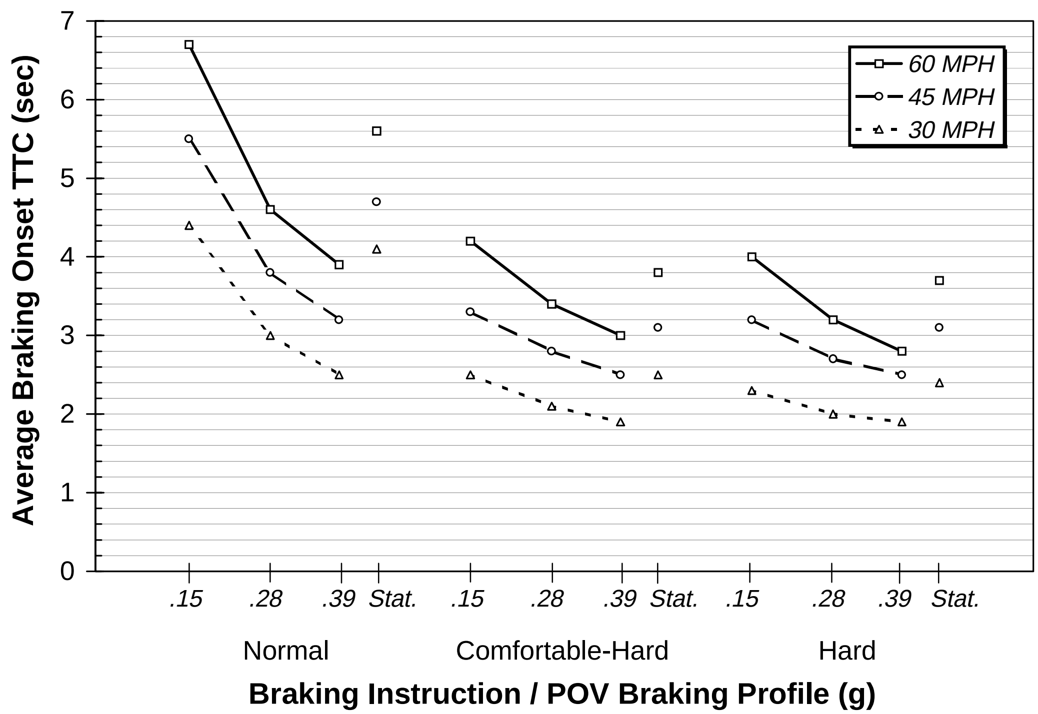


Figure 3-23 Average TTC (Case 2) at SV Braking Onset as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

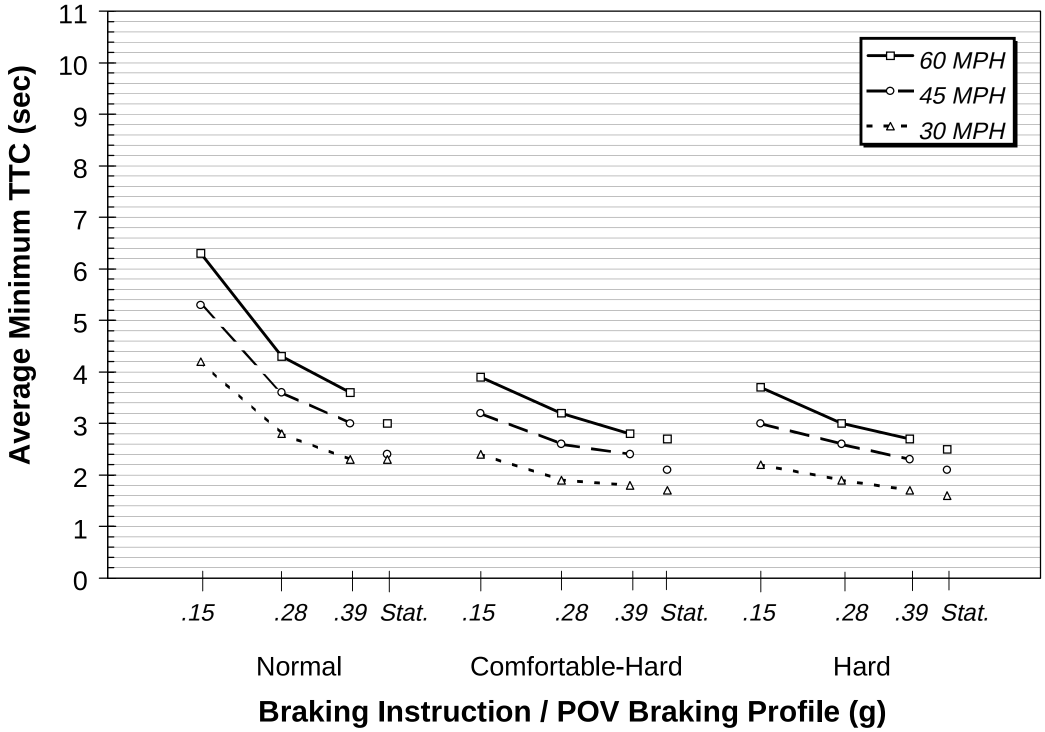


Figure 3-24 Average Minimum TTC (Case 2) Throughout Braking as a Function of Braking Instruction, POV Braking Profile, and Speed Condition

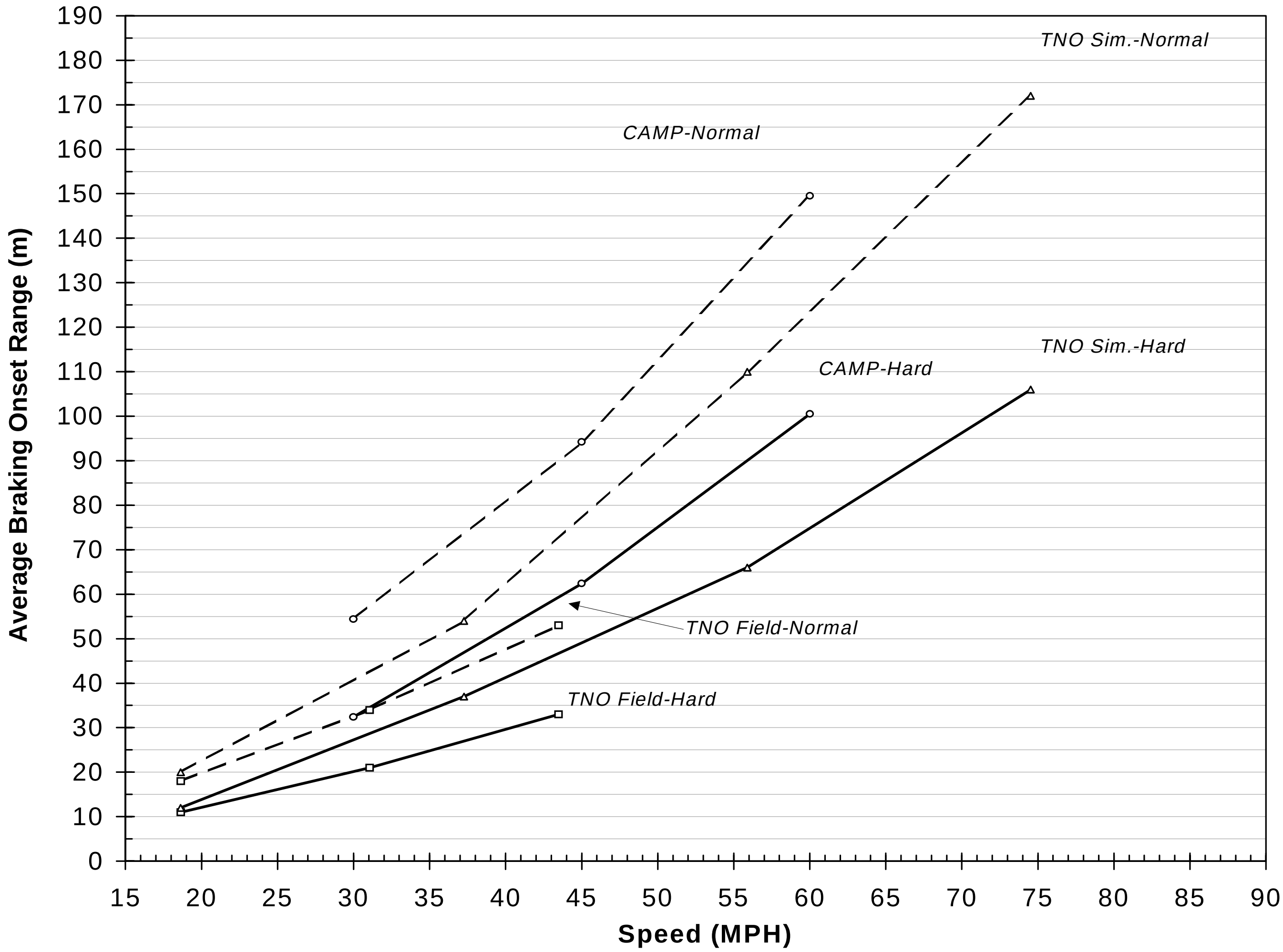


Figure 3-25 Range at Braking Onset for Normal and Hard Braking Instructions During Stationary Trials for the CAMP Study 1, Van der Horst (1990) TNO field study, and Kaptein et al. (1996) TNO Simulator Study

Comparison of Observed Data to Previous “Last-Second” Braking Judgment Data

Methodology of the CAMP Versus TNO Studies

It is worthwhile to compare the results of the current study to previously obtained results under closed-course conditions (van der Horst, 1990) and (fixed-base) driving simulator conditions (Kaptein et al., 1996). These two comparison studies were conducted by researchers at the TNO Institute for Human Factors in Soesterberg, The Netherlands.

In these studies, drivers were tested only under Stationary Trials conditions, and under nearly identical normal and hard braking instruction conditions relative to those used in the current CAMP study (the “comfortable hard” braking instruction was not employed). A few additional important differences between the current CAMP and previous TNO studies are worth stressing before comparing results across studies. First, unlike the current study where drivers were actively involved in controlling their speeds, driver’s speeds in the TNO studies were controlled automatically via cruise control. Second, in the TNO closed-course study, drivers last-second braking judgments were made on an open airstrip (without any driving lane indications) while drivers approached a 2-dimensional Styrofoam mock-up of the rear-end of a vehicle mounted on a plastic barrel. Hence, relative to the current study, drivers’ risk levels were substantially lower for with respect to hitting the target and avoiding the target by either a steering or combined steering/braking maneuver. With respect to the latter point, it should be noted that 1/10 mile markers mounted on metal poles were present on both sides of the test track, which are barely viewable in Figure 3-1 near the bridge underpass. Third, it is important to note that different speed conditions were used across the current CAMP and the two TNO studies, and hence, comparisons across these three studies are not entirely straightforward. Fourth, different age groups were used across the current CAMP and the two TNO studies. However, given the lack of and relatively small magnitude of age effects in the current study, these differences do not appear to be particularly problematic in making comparisons across studies.

Comparison of CAMP Versus TNO Studies Results

The average range at braking onset under normal and hard braking instructions for the current CAMP, and previous TNO closed-course and simulator studies are shown in Figure 3-25. These comparative results indicate that for both the normal and hard braking instruction conditions, average braking onset ranges are substantially longer (and hence, less aggressive/more conservative) in the current CAMP relative to both TNO studies. Under hard braking conditions, the average braking onset ranges in the current CAMP study are approximately 30%-75% longer across the 30-45 mph approach speeds relative to those observed in the TNO closed-course study (van der Horst, 1990). Similarly, the average braking onset ranges in the CAMP study are approximately 20%-35% longer across the 30-60 mph speeds relative to those observed in the TNO simulator study (Kaptein et al., 1996). It is interesting to note that the differences observed under hard braking conditions between the current CAMP and TNO studies increase with approach speeds, where driver’s perceived risk levels may have been higher. In addition to these results, it should be noted that consistent with the current CAMP study, the averaged required deceleration values in the TNO closed-course study increased with approach speeds (the TNO simulator study report does not report these values).

It should be stressed to the results found on the TNO simulator may be idiosyncratic to that particular simulator facility, and so that these results should not be automatically assumed to generalize to other driving simulators. One potential avenue of research, previously suggested by Kaptein et al. (1996) and supported by the current CAMP findings, would be to replicate the current study on a simulator study with motion-base capabilities.

It is interesting to note that based primarily on the two TNO studies discussed above conducted under Stationary Trial conditions, van der Horst and Hogema (1994) recommended as a potential crash alert timing approach to assume a constant 4-second TTC value. This value reflects an assumed (fixed) 1.5 second driver P-RT plus an assumed (fixed) 2.5 second TTC value at braking onset. With respect to this latter assumption, the current results suggest this crash alert timing approach would appear not be appropriate. As can be seen clearly in Figure 3-23, the assumption of a fixed TTC value (in the context of a fixed driver P-RT) appears dubious. Furthermore, even if one focuses on Stationary Trials (i.e., the condition actually tested by TNO), the assumed 2.5 second TTC value at SV braking onset appears to accommodate the *average* TTC-Case 2 values (e.g., rather than 85th percentile value) observed here only in the lowest approach speed condition tested (30 mph). (The reader should note that for Stationary Trials, the TTC-Case 2 measure is equivalent to TTC-Case 1 measure.)

"Real-World Validity" Implications of Differences Observed Across CAMP Versus TNO Studies

Overall, a "*target crash risk*" effects appears to be the most likely explanation for the observed differences across the current CAMP and TNO studies. That is, it appears that under lower target crash risk conditions (e.g., the TNO simulator and TNO closed-course study conditions described above), drivers are willing to begin hard braking later (i.e., at closer ranges to the lead vehicle) than under higher target crash risk conditions (e.g., the current CAMP study conditions). Most importantly, the observed differences suggest that attempts to define crash alert based on research which places drivers under minimal crash risk or no crash risk (e.g., simulator) conditions has the potential to lead to inappropriate and overly aggressive crash alert timing. An error in making the crash alert timing too aggressive in turn leads to the consequence of a decreasing the harm reduction potential of the FCW system. In addition, these results raise serious concerns about the real-world validity of previous FCW interface research which has employed substantially different crash alert timing approaches than suggested by these results (e.g., a fixed TTC criterion) and/or target crash risk conditions which may not be representative of those under which drivers would experience crash alerts (Graham et al., 1995; Hirst & Graham, in press; Janssen & Nilsson, 1990; Janssen & Thomas, 1994; McGehee, et al., 1996; Nilsson et al., 1991).

3.3.4 General Discussion

The primary goal of this initial CAMP study was to build a solid foundation for developing a crash alert timing and interface approach for a FCW system by exploring a number of performance measures. These measures were explored in the context of drivers performing "successful" (crash-free) last second braking maneuvers without a FCW system. In developing a crash alert timing approach for a FCW system, two fundamental parameters involving driver behavior have to be considered. One parameter is the time it takes for the driver to respond to the crash alert and begin braking (e.g., 1.5 seconds), and the second parameter is the driver deceleration (or braking) behavior in response to this alert across a wide variety of initial vehicle-to-vehicle kinematic conditions. This second parameter was the focus of the current study.

Converging evidence suggests that the 50th percentile required deceleration values observed in this study under the hard braking instruction condition appears very promising as an appropriate (not too early/not too late) estimate of the assumed driver braking onset range. The required deceleration level is defined here as the constant deceleration level required for the driver to avoid the crash at braking onset. More precisely, it is the constant deceleration level at braking onset required for the driver to avoid the crash assuming the current speeds of both 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). Since the exact 50th percentile required deceleration values were effected by both speed and lead vehicle deceleration (i.e., the value changed across experimental conditions), modeling work was conducted aimed at predicting these values, which is described in detail in Appendix A20. This appendix also reports modeling efforts aimed at exploring the ability to predict these "last-second", "hard braking" onsets based on a subset of the available "ideal" data described above (e.g., assuming fixed driver and lead vehicle deceleration values).

It should stressed that the common assumption underlying previous crash alert timing approaches was to assume a fixed driver deceleration value independent of these kinematic variables. It is also important to note that the observed average required deceleration values were relatively independent of driver age or gender, which is a desirable characteristic from a FCW system production implementation perspective.

The required deceleration measure were tightly coupled with the actual deceleration measures, where the latter is simply a re-expression of driver's stopping distance given some initial speed. The lack of difference in results found between "comfortable hard" and "hard" braking instruction conditions suggest 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. In addition, driver's were able to maintain the instructed speeds and appeared to follow at "normal" time headways prior to the last second braking judgment. This latter finding provides further evidence that these results found when the lead vehicle was moving may generalize to real-world driving.

In terms of allowing the driver sufficient collision warning distances to avoid a crash, the requirement for FCW sensing range generally increase as the difference in velocities (or delta V) between the following and lead vehicles increases. The 100 meters of sensor "knowledge" accommodates potential crash alert warning distances for completing avoiding a crash for 90% of drivers in the second highest delta V condition tested, which involved the driver approaching the (stationary) parked lead vehicle target at 45 mph. Although the 100-meter criterion fell short in terms of avoiding any crash impact in the highest delta V condition tested (60-mph approach to the parked target). It should be noted that drivers could still experience substantial collision mitigation with a crash alert that is too late for avoiding any crash impact. It should be noted there are a number of caveats associated with this sensing range conclusion, including an assumed 1.7 second combined driver P-RT. Plus delay time, that the road surface coefficient of friction available can support the observed hard braking levels (dry roads were used here), and that drivers can at least match the hard braking levels observed in the current study under real-world conditions in response to a crash alert.

A comparing of these results to previous results obtained at the TNO Human Factors Research Institute (van der Horst, 1990; Kaptein et al., 1996) suggests that attempts to define crash alert timing based on research which places drivers under minimal or no (e.g., simulator) crash risk conditions the potential to lead to overly aggressive crash alert timing. This type of error could in turn lead to the consequence of decreasing the harm reduction potential of the FCW system. In addition, these results raise serious concerns about the real-world validity of previous FCW interface research which has employed substantially different crash alert timing than suggested by these results (e.g., a fixed 4-seconds time-to-collision criterion) and/or target crash risk conditions which may not represent those under which drivers would experience crash alerts (Graham et al., 1995; Hirst & Graham, in press; Janssen & Nilsson, 1990; Janssen & Thomas, 1994; McGehee, et al., 1996; Nilsson et al., 1991).

The results of this study were used in the three subsequent driver interface studies for crash alert timing purposes. More specifically, these results, and the subsequent modeling of these Study 1 results (see Appendix A20) aimed at predicting required deceleration values, formed the basis for assumptions regarding the assumed driver deceleration (or braking) behavior in response to the FCW crash alert in the subsequent driver interface studies. These interface studies focused on how to present a crash alert to the driver (i.e., visual, auditory, and/or haptic alerts), and provided an important opportunity to evaluate and validate these deceleration-based crash alert timing approach assumptions.

3.4 Abstract for Study 2, Study 3, and Study 4 - The Interface Studies

The goal of the human factors portion of the CAMP project was to define driver-interface requirements. More specifically, this effort is focused on defining when to present crash alerts (i.e., the crash alert timing) and how to present crash alerts to drivers (i.e., the crash alert modality). Developing a crash alert timing approach was the focus of Study 1, and the following three driver interface studies focused on how to present a crash alert to the driver (i.e., visual, auditory, and/or haptic alerts). These driver interface studies also provided an important opportunity to evaluate and validate the crash alert timing approach developed in Study 1. *The critical need for obtaining these data is dictated by the absence of data under controlled, realistic conditions involving drivers braking to a realistic crash threat while experiencing production-oriented crash alerts.*

In developing a crash alert timing approach for a Forward Collision Warning (or FCW) system, two fundamental parameters involving driver behavior need to be assumed. These parameters serve as input into straightforward vehicle kinematic equations that determine the alert range necessary to avoid a crash.

The first parameter is the time it takes for the driver to respond to the crash alert and begin braking (which included *driver brake reaction time*), and the second parameter is the driver deceleration (or braking) behavior in response to this alert across a wide variety of initial vehicle-to-vehicle kinematic conditions. Defining this second parameter of driver behavior was the focus of CAMP Study 1. In this 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 of this experimental strategy is that properly characterizing (i.e., modeling) the kinematic conditions surrounding these 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 CAMP Study 1 is subsequently referred to as the "baseline" study.

The second fundamental crash alert timing parameter involving driver behavior which needs to be considered in developing a crash alert timing approach is driver brake reaction time (or *driver brake RT*). This second parameter was addressed in the three closed-course, field studies (all conducted at the GM Milford Proving Ground) reported here in the presence of various FCW system crash alert types under *unexpected (or surprise) braking event conditions*, which are discussed below.

The three driver interface studies reported here focused on how to present a crash alert to the driver (i.e., visual, auditory, and/or haptic alerts), and provided an opportunity to evaluate and validate the deceleration-based crash alert timing approach assumptions developed from the baseline study (i.e., the required deceleration parameter-based Study 1 predictive equation coupled with a driver brake RT assumption). With respect to the latter point, results clearly indicated that the deceleration-based timing approach employed was subjectively rated by drivers (on average) as “just right” timing under a wide range of combinations of driver speed and lead vehicle decelerations under both expected and surprise braking event conditions. Most importantly, this crash alert timing approach allowed drivers to respond to the crash alert in a manner which allowed them to avoid impacts with the surrogate lead vehicle (or surrogate target).

Across these driver interface studies, younger, middle-aged and older drivers were tested. Drivers were asked to brake in response to various FCW system crash alert types while approaching the slowing or stopped surrogate target. Both alerted and unexpected (or surprise) braking event conditions were investigated with both trained and naive drivers. In two of the three studies, drivers were completely unaware the vehicle was even equipped with a FCW system crash alert prior to the unexpected, surprise braking event. 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 were employed to create a relatively “inattentive” driver including 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.

Across these 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 that were tested are indicated below:

- Head-Up + 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 High Head-Down Display 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 (a “car-star-car” crash icon with the word “WARNING” printed below) was selected from a set of alternatives by using an established ANSI procedure for evaluating candidate symbols. 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. The haptic alert evaluated was a brief brake pulse, or “vehicle jerk” alert. This alert was examined with more intent to explore its potential, since unlike the visual and auditory alerts examined here, there are important unresolved implementation issues surrounding this alert.

The key dependent measures were drivers' brake RTs (particularly during surprise braking event conditions), drivers' required and actual (or observed) decelerations in response to the crash alerts, the extent to which drivers noticed the various crash alerts under surprise braking event conditions, and drivers' subjective ratings of both the crash alert timing and FCW system crash alert types examined.

Results indicated differences in both objective (performance) data and subjective (questionnaire-oriented) data across the crash alert types examined. The key findings were as follows. First, the crash alert type conditions including a non-speech tone component resulted in faster brake RTs relative to the crash alert type including a speech component. Second, drivers rated the crash alert types including either a speech or brake pulse component as more annoying relative to the remaining crash alert types, under the assumption that FCW system crash alerts would occur in non-threatening situations between once a day to once a week. Third, the brake pulse alert provided a "vehicle slowing" advantage during the delay time interval between when the crash alert timing was violated and when the driver braked, such that the driver was in a more conservative kinematic scenario at braking onset relative to the crash alert types examined not including this alert component. Furthermore, adding a non-speech tone component to the brake pulse alert significantly reduced the relatively slow brake RTs initially observed in the HHDD + Brake Pulse condition. Fourth, although there were no performance differences associated with the relevant HHDD versus HUD comparisons, subjects indicated a strong preference for the HUD. In a related finding, for a 1-stage crash alert approach, drivers indicated a strong preference for a multi-modality crash alert approach (particularly a dual-modality crash alert approach). Fifth, after the surprise braking event was experienced by naive drivers, nearly all drivers reported noticing non-speech tone, speech, and brake pulse components of these crash alert types examined, and significantly more drivers noticed the Flashing HHDD and steady HUD relative to the steady HHDD.

In addition to these crash alert modality (or crash alert type) differences, brake RTs observed under the surprise technique which resulted in the highest upper percentile values (the head-down visual search task) yielded 85th to 95th percentile (i.e., slower) RTs of 1.2 and 1.5 seconds, respectively.

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 is (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 Adaptive Cruise Control 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.

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).

Based primarily on data from these three interface studies and the previous baseline study (CAMP Study 1), a set of minimum driver interface requirements were developed, which are discussed in Chapter 4.

3.5 Introduction for Interface Studies

Purpose of CAMP Human Factors Studies 2, 3, and 4

This research describes three closed-course, field studies aimed at exploring human factors issues surrounding forward collision warning systems (i.e., the effects of this collision warning system and associated interfaces on driver behavior). More specifically, this research explored human factors issues surrounding *Forward Collision Warning* (or *FCW*) systems which have not been adequately addressed by the relatively limited number of previous human factors studies conducted either under laboratory conditions (Graham, Hirst, & Carter, 1995; Hirst & Graham, in press) or driving simulator conditions (Janssen & Nilsson, 1990; Janssen & Thomas, 1994; McGehee, Dingus, & Wilson, 1996; Nilsson, Alm, & Janssen, 1991).

Overall, this CAMP human factors effort is focused on defining <u>when</u> to present crash alerts (i.e., the crash alert timing) and <u>how</u> to present crash alerts to drivers (i.e., the crash alert modality) by exploring a number of objective and subjective driver measures. *The critical need for obtaining these data is dictated by the absence of data under controlled, realistic conditions involving drivers braking to a realistic crash threat while experiencing production-oriented crash alerts.* In CAMP Study 1, 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 of this experimental strategy is that properly characterizing (i.e., modeling) the kinematic conditions surrounding these 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.

As was noted above, previous research examining FCW system interfaces (and timing) have been conducted under either laboratory or driving simulator conditions, and these results have not been validated under real-world driving conditions. A comparison of CAMP Study 1 results to previous driving simulator research suggested that attempts to define crash alert timing under conditions which place drivers under minimal or no crash risk conditions (e.g., driving simulator conditions) has potential to lead to overly aggressive crash alert timing. This type of error could in turn lead to the consequence of decreasing the harm reduction potential of the FCW system. In addition, this comparison raises serious concerns about the real-world validity of previous FCW system interface research which has employed substantially different crash alert timing than that suggested by the CAMP Study 1 results (e.g., a fixed 4-seconds time-to-collision criterion) and/or target crash risk conditions which may not represent those under which drivers would experience crash alerts.

In developing a crash alert timing approach for a FCW system, two fundamental parameters involving driver behavior need to be assumed. These parameters serve as input into straightforward vehicle kinematic equations that determine the alert range necessary to avoid a crash. The first parameter is the time it takes for the driver to respond to the crash alert and begin braking (which includes *driver brake reaction time*), and the second parameter is the driver deceleration (or braking) behavior in response to this alert across a wide variety of initial vehicle-to-vehicle kinematic conditions. Defining this second parameter of driver behavior was the focus of the CAMP Study 1, during which drivers performed "last second" braking without the benefit of FCW system support. This study is subsequently referred to as the "baseline" study. The second fundamental crash alert timing parameter involving driver behavior, which needs to be considered in developing a crash alert timing approach is: driver brake reaction time (or *driver brake RT*). This second parameter was addressed in the three closed-course, field studies (all conducted at the GM Milford Proving Ground) reported here in the presence of various FCW system crash alerts under *surprise braking event conditions*, which are discussed below.

The three driver interface studies reported here focused on how to present a crash alert to the driver (i.e., visual, auditory, and/or haptic alerts), and provided an opportunity to evaluate and validate the crash alert timing approach assumptions developed from the baseline study (i.e., the required deceleration parameter-based Study 1 predictive equation coupled with a driver brake RT assumption).

3.6 Overview of Methodological Approach for Interface Studies

Overall, the goal of the current studies is to gather data of the highest real-world validity possible under controlled closed-course conditions. An overview of the experimental methodology and approach used in the three studies described below is shown in Table 3-11, and an overview of the order of experiment events (or procedures) in these three studies is shown in Table 3-12. For each of these studies, data was gathered on the same 1-mile straightaway and under the same general vehicle-to-vehicle spacing conditions which were used for CAMP Study 1.

Across these driver interface studies, younger, middle-aged and older drivers were tested under closed-course field conditions. Drivers were asked to respond to various FCW system crash alerts while approaching the slowing or stopped surrogate target. Both alerted and unexpected (or surprise) braking event conditions were investigated with both trained and naive drivers. In two of the three studies, drivers were completely unaware the vehicle was even equipped with a FCW system crash alert prior to the unexpected, surprise braking event. Several strategies were employed to ensure the driver experienced the crash alert (i.e., the criterion for triggering the alert was met) during the surprise braking event conditions and to create a relatively “inattentive” driver. Strategies used to create an inattentive driver included engaging the driver in natural conversation (used in Study 2), asking the driver to respond to some background-type questions (used in Study 3), and asking the driver to search the head-down, conventional instrument panel for a (non-existent) indicator light (used in Study 4).

During this unexpected, surprise braking event, the lead vehicle traveled at 30 mph and braked at 0.36-0.38 g’s without brake lights activated (average lead vehicle deceleration values caused by the “automatic” brake controller varied slightly across studies). The rationale for choosing this lead vehicle speed and deceleration conditions were two-fold. First, for safety reasons, it was felt the surprise event should be run initially at the lowest speed condition tested (i.e., 30 mph). Second, 6 surrogate target impacts occurred in CAMP Study 1, which can be thought of as a failure to execute appropriate braking by both the driver and experimenter (the latter who had access to add-on brakes). Of the 12 distinct lead vehicle speed/lead vehicle deceleration combinations investigated in CAMP Study 1, 4 of the 6 impacts occurred in the 30 mph /-0.39 g combination condition. Hence, it appears this scenario may be particularly problematic for making appropriate “last-second” hard braking judgments. These surprise braking event conditions (i.e., the POV speed and POV deceleration profile) were held constant across each of the three studies reported, and are subsequently referred to collectively as the *Surprise Moving Trial*. Drivers were also asked to repeat the surprise braking event condition as an alerted driver for comparison purposes.

Table 3-11 Overview of Study 2, Study 3, and Study 4 Methodology

Method Issue	Study 2	Study 3	Study 4
Subjects from CAMP Study 1?	Yes	No	Yes
Number of younger/middle/ older aged subjects tested (Gender split)	8 / 8 / 8 (n=24)	0 / 30 / 30 (n=60)	8 / 8 / 8 (n=24)
Study Phases	(1ST) Alerted Stationary (2ND) Surprise Moving (3RD) Follow-on Moving	(1ST) Surprise Moving (2ND) Follow-on Moving	(1ST) Surprise Moving (2ND) Alerted Moving
Instructions During Alerted Trials	Maintain steady speed (during Stationary Trials) or follow normally (during Moving Trials). Brake immediately in response to crash alert in order to avoid crash.		
Alerted Trials Scenarios	Approach parked car at 30 or 60 mph. Crash alert timings used: "RDP", "RDP + 0.05 g", "RDP + 0.10 g". Driver RT = 0.52 sec.	Not applicable.	Approach moving car traveling at 30, 45, or 60 mph. Lead car brakes at either -0.15, -0.27, or -0.36-0.38 g's. "RDP" timing used. Driver RT = 0.52 sec.
Surprise Moving Trial Technique	Natural Conversation	Background Q & A	Head-Down Telltale Search
Surprise / Follow-On Trials Scenario	Lead vehicle travels at 30 mph and brakes at -0.36 to -0.38 g's without brakelights. "RDP" crash alert timing used. Driver RT assumption = 1.5 seconds for Surprise trial.		
Crash Alert Types Tested (1-stage, primarily dual-modality)	HUD + Non-Speech HHDD + Non-Speech HHDD + Speech HHDD + Pulse	→ → → HHDD + Pulse + Non-Speech Flashing HHDD + Non-Speech	→ →
"Key" Dependent Measures	Brake RT, Required deceleration, Actual deceleration, Crash alert timing and Interface appropriateness ratings, and Visual telltale noticeability		

Table 3-12 Procedure Orders for Study 2, Study 3 and Study 4

Performance Data	Brief Procedure Description	Study		
		2	3	4
Alerted Stationary Trials	4 blocks of 6 trials; a different crash alert type used for each block. Alerted driver approaches parked surrogate target at either 30 or 60 mph, and brakes to alert.	1		
Surprise Moving Trial	One trial; POV speed 30 mph, POV deceleration –0.36 to –0.39g, no POV brakelights. Unexpected (or surprise) braking event triggers alert. Various driver distraction techniques employed.	2	1	1
Alerted Moving Trials	18 trials varying speed, POV deceleration, and crash alert timing. Alerted driver follows moving surrogate target, and brakes to alert when target slows.			2
Follow-on Moving Trials	Trials following surprise trial. Conditions identical to Surprise Moving Trial except driver is alerted to braking event.	3	2	
Subjective Data				
Alert Noticeability Questionnaire	Naive participant reported alerts noticed during post-Surprise Moving Trial interview.		1[a]	1[a]
Timing Rating	Participant rated crash alert timing on a scale ranging from 1 (much too early) to 7 (much too late).	1[a], 2[a], 3[a]	1[a],2[a]	1[a],2[a]
Alert Modality Appropriateness Questionnaire	Participant rated modality-specific characteristics of alert (e.g., brightness, duration, intensity).	1[b]	2[b]	
Crash Alert Appropriateness Questionnaire	Participant rated warning characteristics of multi-modality crash alert types experienced (e.g., confusability, annoyance, startle).	4	3	
Build an Interface Questionnaire	Participant selected preferred alert(s) under 1-stage alert assumptions, and then under 2-stage alert assumptions.	5		
Name the System Questionnaire (open-ended)	Participant generated possible name for alert system.	6		
Name the System Questionnaire (forced choice)	Participant chose three preferred names for alert system from a list of names.	7	4	

[a]Refers to subjective data gathered on corresponding "performance data" trial.
[b]The Alert Modality Appropriateness Questionnaire was completed for each alert type after each block of trials.

Across these driver interface studies, six separate crash alerts 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 visuals alert components evaluated included a "high" head-down display and a head-up display (or HUD). The visual format of these displays (a "car-star-car" crash icon with the word "WARNING" printed below) was selected from a set of alternatives by using an established ANSI procedure for evaluating candidate symbols. 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. The haptic alert evaluated was a brief brake pulse, or "vehicle jerk" alert. This alert was examined with more of an intention to explore its potential, since unlike the visual and auditory alerts, there are important unresolved implementation and driver behavior issues surrounding this alert.

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. 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 that this required deceleration-based estimate would ensure that, for a high percentage of drivers, the onset of braking in response to a crash alert would:

1. Occur at a closer range than their braking onset range during "aggressive" normal braking.

2. 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 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 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 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, Kotwal, Lyons, and Gardner-Bonneau (1996) for 2-stage automotive crash alerts was based on research examining aircraft alerting systems, which may have very different alert timecourses (e.g., slower-developing timecourses) 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.

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, and that adding a (non-omnidirectional) visual crash alert was a prudent strategy for a crash alert modality approach. With respect to the former point, an omnidirectional alert component is required since an inattentive or distracted driver (who play large roles in rear-end collisions) 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. With respect to this latter point, 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. For these reasons, a visual alert (either a "high" head-down display or head-up display) was always included as a component in each of the multi-modality (either dual-modality or tri-modality) crash alert types investigated.

Various objective measures were analyzed. The key dependent measures were drivers' brake RTs (particularly during the Surprise Moving Trial). Drivers' required and actual (or observed) decelerations in response to the crash alerts, the extent to which drivers noticed the various crash alerts under the Surprise Moving Trial conditions, and drivers' subjective ratings of both the crash alert timing and FCW system crash alert types examined. The variable definitions, and the point in time during the braking maneuver in which the performance measures were analyzed (at POV braking onset, at SV braking onset, throughout the braking, end of the braking maneuver) are identical to that used in Study 1, with the exception of one new measure, driver's brake reaction time (RT). This measure is defined as the time between crash alert onset and the driver contacting the brake (i.e., triggering the brake switch) in response to the alert. (Also, it should be noted that unlike CAMP Study 1, SV braking onset was defined relative to the brake switch trigger point, since drivers braked in a “crisp”, firm manner in response to the alert (rather than sometimes hovering over the brake as was observed during “last-second” braking judgments in CAMP Study 1).

3.7 Study 2 Experimental Methodology and Approach

Braking in Response to Expected FCW Crash Alerts Under Lead Vehicle Stationary Conditions / Unexpected Braking Event

Building upon the solid foundation provided by the results obtained from CAMP Study 1, this study examined how and when to present crash alert information to both an attentive and relatively inattentive driver. An overview of the experimental methodology and approach used in this study is shown in Table 3-11, and an overview of the order of experiment events (or procedures) in this study is shown in Table 3-12. A subset of the test participants used in CAMP Study 1 was tested. Drivers in this study were fully informed that the purpose of the study was to address the usefulness of FCW system crash alerts for helping drivers avoid rear-end collisions.

In this study, drivers were asked to brake in response to a FCW system crash alert as an attentive driver while approaching the stationary (or parked) surrogate target at a steady speed of either 30 or 60 mph. These types of trials are subsequently referred to as *Alerted Stationary Trials*. These two lead vehicle stationary conditions were previously examined in CAMP Study 1. Hence, driver's braking behavior with a crash alert could be compared to previous data obtained under identical conditions without a crash alert (for the same driver), which is discussed toward the end of this Chapter immediately prior to the General Discussion section. Three different crash alert timing approaches were examined. Immediately after a trial, drivers were asked to judge the appropriateness of the FCW system crash alert timing with the following 7-point scale:

What is your opinion about when the crash alert was presented?

1	2	3	4	5	6	7
Much Too Early	*Moderately Early*	*Slightly Early*	*Just Right*	*Slightly Late*	*Moderately Late*	*Much Too Late*

When the test was allegedly over, the Surprise Moving Trial was introduced. The *surprise trial technique* involved the backseat-experimenter engaging the driver in "semi-structured", context-appropriate, natural, non-suspicious dialog. This type of trial is subsequently referred to throughout this paper as the *Surprise Moving Trial*. This Surprise Moving Trial was then followed by two comparable alerted trials with the same alert type. These types of trials will be subsequently referred to throughout this paper as *Follow-On Moving Trials*.

Four different, 1-stage, dual-modality crash alert types were investigated, which were each examined with three different crash alert timing approaches. The timing of the crash alert information was based on modeling results from CAMP Study 1, explained in further detail below. For the Alerted Stationary Trials and Follow-On Moving Trials, driver brake RT was assumed to be 0.52 seconds, based on piloting work conducted with four drivers. This driver brake RT was intended to allow an alerted driver to experience hard braking onset at the range predicted based on the modeling of Study 1 findings (discussed below). For the Surprise Moving Trial, driver brake RT was assumed to be 1.50 seconds. Similarly, this driver brake RT was intended to allow an inattentive or distracted driver to experience hard braking onset at the range predicted based on the modeling of Study 1 findings (discussed below). Olson (1996) states that for "reasonably" straightforward situations, 85%-95% of drivers will respond with a perception-response time of 1.5 seconds or less after the first appearance of the object or condition of concern. This tentatively suggested that a 1.5 second assume driver brake RT value would be a good choice for allowing ample time for the vast majority of drivers to brake to avoid a rear-end collision, but the trade-off between this perception-RT value and avoiding excessive in-path nuisance (or 'too early") alerts remains unclear.

3.7.1 Subjects

Test participants consisted of four males and four females in each of three different age groups; 21-31, 41-51, and 61-67 years old. Corresponding mean ages for these three groups were 26, 46, and 64 years old, respectively. Each driver was tested individually in one approximately 2 to 2 ½ hour sessions and paid $150 for their participation. Drivers were recruited by an outside market research recruiting firm, and were required to be CAMP Study 1 participants. Drivers who were ultimately allowed to participate were mailed the information letter shown in Appendix A1 prior to testing. A copy of the informed consent statement is provided in Appendix A2, which describes the various conditions that ruled out potential drivers from participating (which were nearly identical to the conditions used in CAMP Study 1).

3.7.2 Test Site

Data was gathered on the same straightaway used in CAMP Study 1. The road was closed to all other traffic during testing. All testing was conducted under daytime conditions under dry road and dry weather conditions.

3.7.3 Test Vehicles and the "Surrogate" (Lead Vehicle) Target

The driver's (or subject's) vehicle, the mock-up surrogate lead-vehicle and the lead (tow) vehicle were identical to those used in CAMP Study 1. These three primary elements of the experimental apparatus will be subsequently referred to as the *subject vehicle (SV), surrogate target,* and *principal other vehicle (POV),* respectively.

The SV front seat, passenger-side experimenter and POV driver were trained General Motors Milford Proving Ground test drivers who had previous experience conducting brake tests. The SV and the POV test drivers communicated during the study via digital radio communication.

3.7.4 Data Acquisition System

The data acquisition system used was identical to that used in CAMP Study 1, with the exception of the changes noted below.

Instrumentation

The two computers, one in each car, were linked together using a wireless local area network (or LAN). This link was used to control the beginning and end of a test trial. In addition, information about POV speed and POV acceleration levels were transferred to the SV. VI Engineering using National Instrument Labview Software developed the data acquisition program. The signal-conditioning interface (N.I. SCXI) was changed relative to Study 1 to provide more inputs and outputs to accommodate the various crash alert modality components. Figure 3-26 provides concept or block diagrams of the SV and POV instrumentation. Figure 3-27 shows the position of some of the main pieces of equipment installed in the vehicles. The equipment in the trunk was mounted in a rack to prevent sliding. The computer was mounted on a pedestal in the back seat along with the video monitor. The antennas were fastened to the rooftop above the rear seat. Table 3-13 provides a detailed list of POV and SV instrumentation used during the testing. Items in this table listed with no cost were provided by the CAMP partner companies (GM or Ford).

Figure 3-26 Concept Diagrams of the Subject Vehicle and Principal Other Vehicle Instrumentation

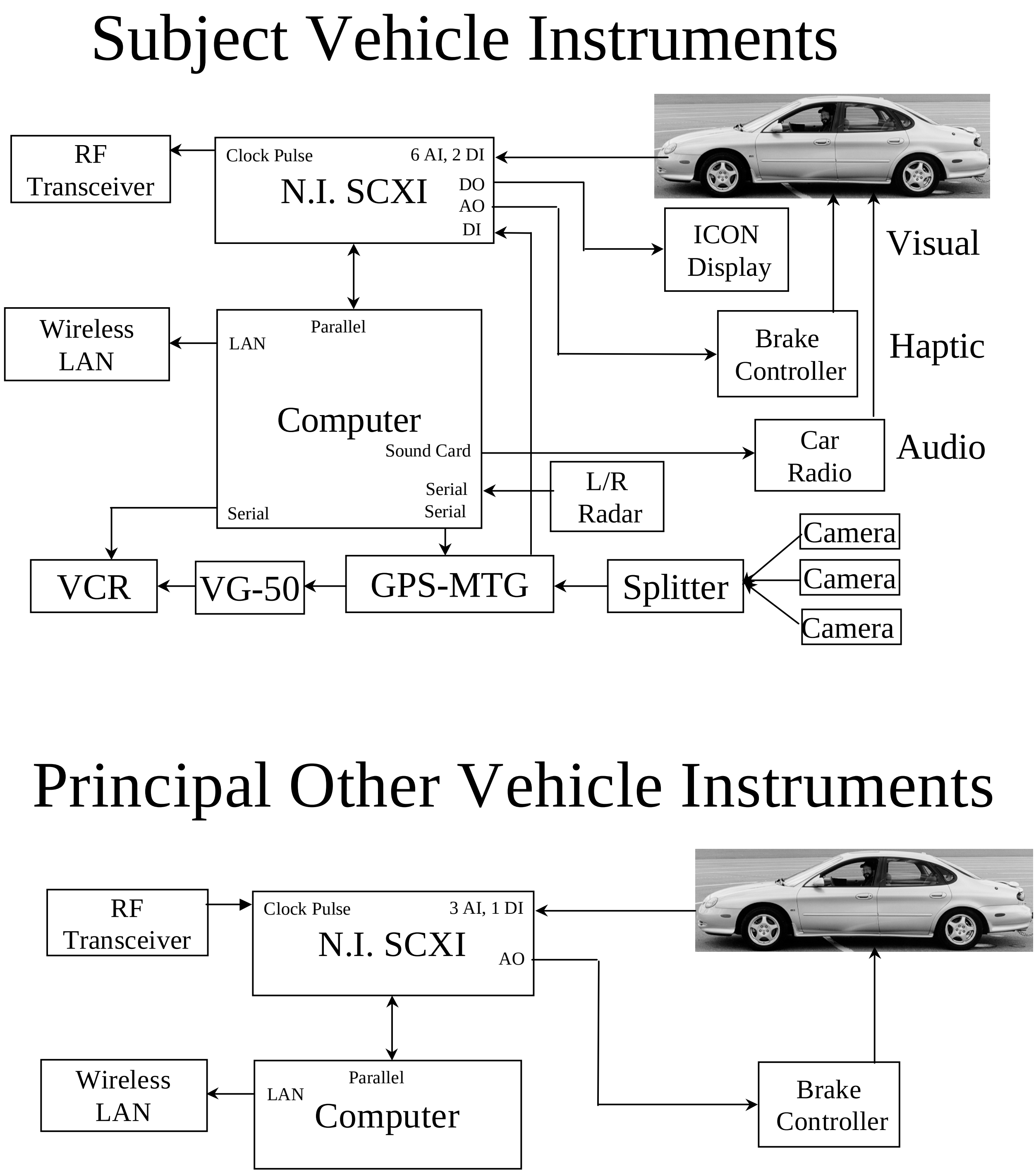


Figure 3-27 Illustration of Equipment Installations

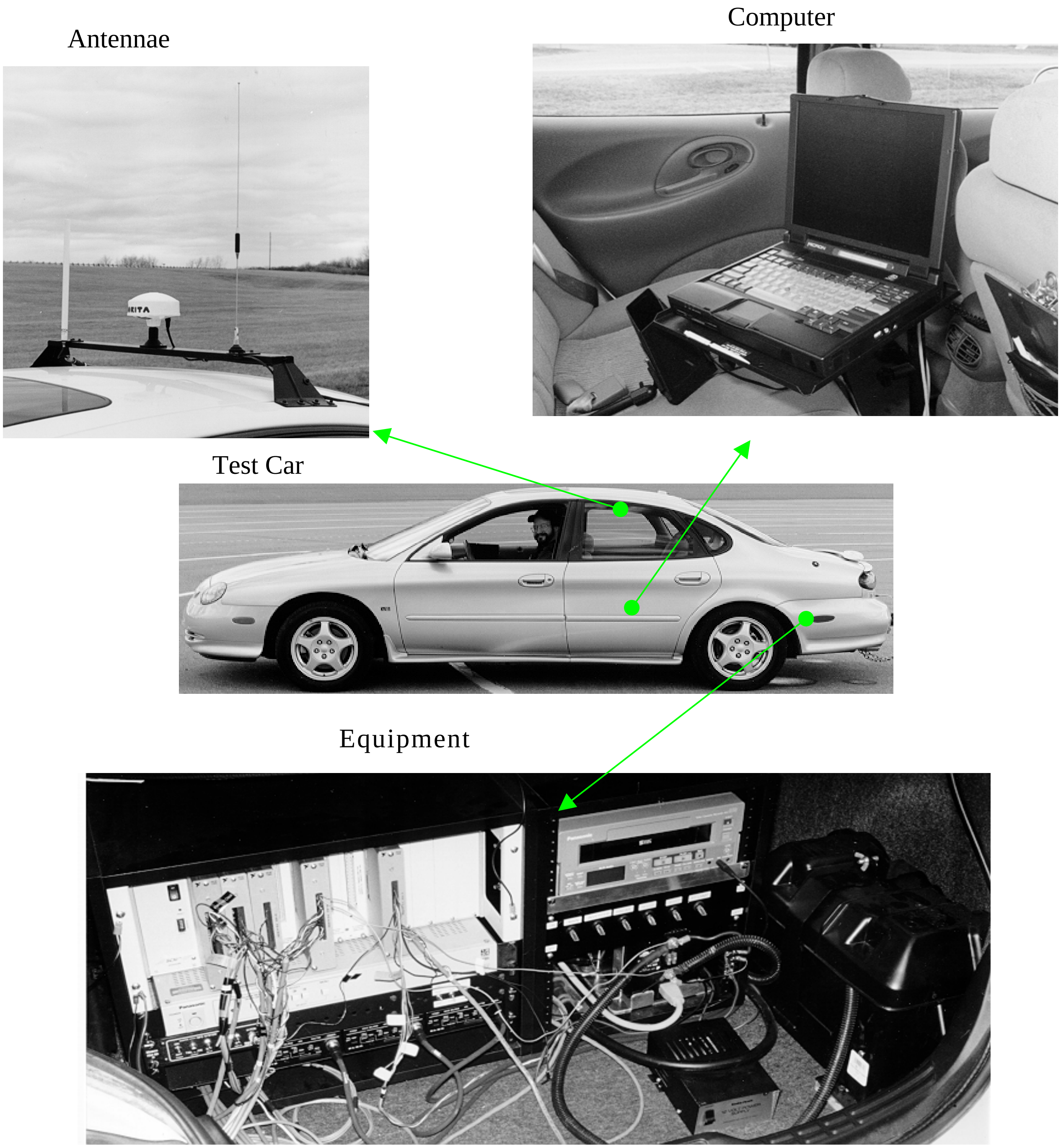


Table 3-13 Equipment List for the Subject Vehicle (SV) and the Principal Other Vehicle (POV)

SV Instruments	Manufacture	Model	Serial Number	Cost
Test Car	Ford Motor Company	1997 White Taurus SHO	1FALP54N9VA 140762	$15,000
Power Inverter	Trip Lite	PV-400		$170
Signal chassis	National Instruments	SCXI chassis		$11,000
Distance Sensor	Mitsubishi Laser Radar Control Unit, Head	EMZ503-01 X4T25571T1	001	$3,300
Passenger Brake	Safety Industries	Titan Dual Control Brake		$620
Video Monitor	Citizen	M398	C6-02692	$280
VCR	Panasonic	AG-5700-P	16TB00090	$1,450
4 to 1 Video	Panasonic Quad System	WJ-420	6ZB22758	$1,250
Camera	Elmo	MN401E Camera	131879, 131862, 131842	$7,800
Time Code Generator	Horita	RM-50II GPS	MT-4393033	$1,800
Time Code Converter	Horita	VG-50	VB-757850	$265
GPS Receiver	Hortia	28529-61	0260034705	$1,215
Computer	Micron	NBK001221-00	758041-0001	$4,800
Computer desk	Mobile Planet	MP320101 Mobile desk		$180
Accelerometer	Lucas Schaevitz,	LSBP-1	38922	$0
Load Cells	Entran Sensors	ELF-1000I-100	96L96L17-Y16,Y21,Y17	$2000
Position Transducer	SpaceAge Control	160-1215	4580	$574
Heads-Up-Display	Delco Electronics	Eye-Cue 2000	002	$1500
High-Head-Down Display	General Motors	HHDD		$0
Brake Pulse	Delphi	Brake Pulse System		$39,984

POV Instruments	Manufacture	Model	Serial Number	Cost
Test Car	Ford Motor Company	1997 Silver Taurus SHO	1FALP54N7VA 140761	$15,000
Power Inverter	Trip Lite Power	PV400		$170
Signal Chassis	National Instruments	SCXI chassis		$11,000
Brake Booster	ITT Industries	Analog Booster System	3-33826-69	$37,561
Trailer Brake	Kelsey Energize	Electric Brake Control Unit		$0
Computer	Micron	NBK001221-00	758041-0002	$4,800
Computer desk	Mobile Planet	MP320101 Mobile desk		$180
Accelerometer	Lucas Schaevitz	LSBP-1	38923	$0
Accelerometer	Valentine Research	G-analyst	3035000200	$0
	Valentine Research	G-analyst display	0774000100	$0
Radio	NexTel	I370XL	089AXYK475	$201
	FJW Industries	Find-R-Scope	9082	$0
Accelerometer	Valentine Research	G-analyst	8925000200	$0
	Valentine Research	G-analyst display	5774000100	$0

3.7.5 Visual, Auditory and Brake Pulse Crash Alert Modality Components

The driver was simultaneously presented crash alerts from two sensory modalities, sometimes referred to as a *1-stage, dual-modality crash alert*. The modality components of the various crash alerts examined are described below.

Visual Crash Alert Modality Components

The high head-down display was placed on top of the instrument panel, close to the cowl of the windshield, and centerline to the driver. This display was supplied by GM, and is shown in the top half of Figure 3-28. This figure illustrates the visual display format resulting from the visual icon selection process, which is explained, in detail in Appendix A18. The crash alert icon (a "half car-star-half car" symbol) and the word "WARNING" (printed below) appeared as amber on a black background. With respect to the eyellipse centroid, the following discussion provides specific information on the position and size of this high head-down display visual crash alert. 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 (i.e., where the hood visually occludes the roadway) was also 7.7^0, and the look-down angle to the center of the instrument panel cluster was 19.3^0. The area encompassed by both the visual icon (a "half car-star-half car" symbol) and the word "WARNING" subtended a 0.8^0 high by 1.2^0 wide visual angle area. The area encompassed by the visual icon subtended a 0.3^0 high by 0.9^0 wide visual angle area. The area encompassed by the capitalized word "WARNING" subtended a 0.2^0 high by 1.2^0 wide visual angle area. These capitalized letters were 3 millimeters in height, and printed in Helvetica bold font type.

The high head down display module consisted of four lamps enclosed in a machined aluminum housing with baffles positioned between the lamps. The exterior was painted black, and the inside was a white color. The lamps were mounted on a printed circuit board that slides into the housing from the front. The panel with the crash alert icon was plastic and snapped into the front of the housing. Four icons were selected and sized to be placed on a Polycarbon material, which was done by Lettergraphics of Detroit. These icons were selected based on results from the comprehension estimation procedure during the first phase of the visual icon selection procedure. The operation of the lamps was controlled through a signal-conditioning interface. A breadboard of relays was built to switch the lamps. The relays were driven by digital TTL signals, which provided the ability to flash the icon.

The head-up display (or HUD) was projected off a combiner as a virtual blue/green image and appeared below the driver's line of sight and centerline to the driver. The format of the HUD crash alert was identical to that used with the high head-down visual display, which is shown in the bottom half of Figure 3-28. (The reader should note that the HUD photograph in this illustration was taken off center.) With respect to the eyellipse centroid, the following discussion provides specific information on the position and size of this HUD crash alert. The HUD appeared at approximately a 1.214-meter image distance. The area encompassed by both the visual icon and the word "WARNING" subtended a 1.4^0 high by 3.4^0 wide visual angle area. The

Figure 3-28 Illustrations of the High Head-Down Display (HHDD) and the Head-Up Display (HUD) Visual Crash Alerts

area encompassed by the visual icon subtended a 0.7^0 high by 2.5^0 wide visual angle area. The area encompassed by the capitalized word "WARNING" subtended a 0.5^0 high by 3.4^0 wide visual angle area. 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 this aftermarket HUD 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 (i.e., where the hood visually occludes the roadway), 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 4^0-5^0.

This head-up display was an after-market Eye-Cue 2000 HUD product offered by Delco Electronics. The display is an 80 by 40 pixel display with plastic housing and combiner glass, and a separate DC to DC power supply. A controller to drive the display was developed by Danlaw Incorporated. The controller, a Motorola 68HC11, was programmed to display various crash alert icons, as well as a "CAMP" test image. Four digital TTL input lines were used to select which icon to display. The intensity (or brightness) of the display was controlled by a knob on the right side of the housing, which can be seen in Figure 3-28. The vertical location of the HUD image in the driver's field of view was controlled by tilting the combiner glass in a fore/aft motion. As can be seen in Figure 3-28, this aftermarket HUD unit was mounted on top of the instrument panel in front of the driver. Figure 3-29 illustrates the interconnections of the HUD components, HUD, power supply, and the controller.

Hence, overall, the HUD visual crash alert subtended a larger visual angle than the HHDD visual crash alert in both the height and width dimensions. In addition, the HUD appeared at approximately half the look down angle relative to the HHDD (or put in another way, the HUD appeared twice as close to the driver's visual horizon).

Auditory Crash Alert Modality Components

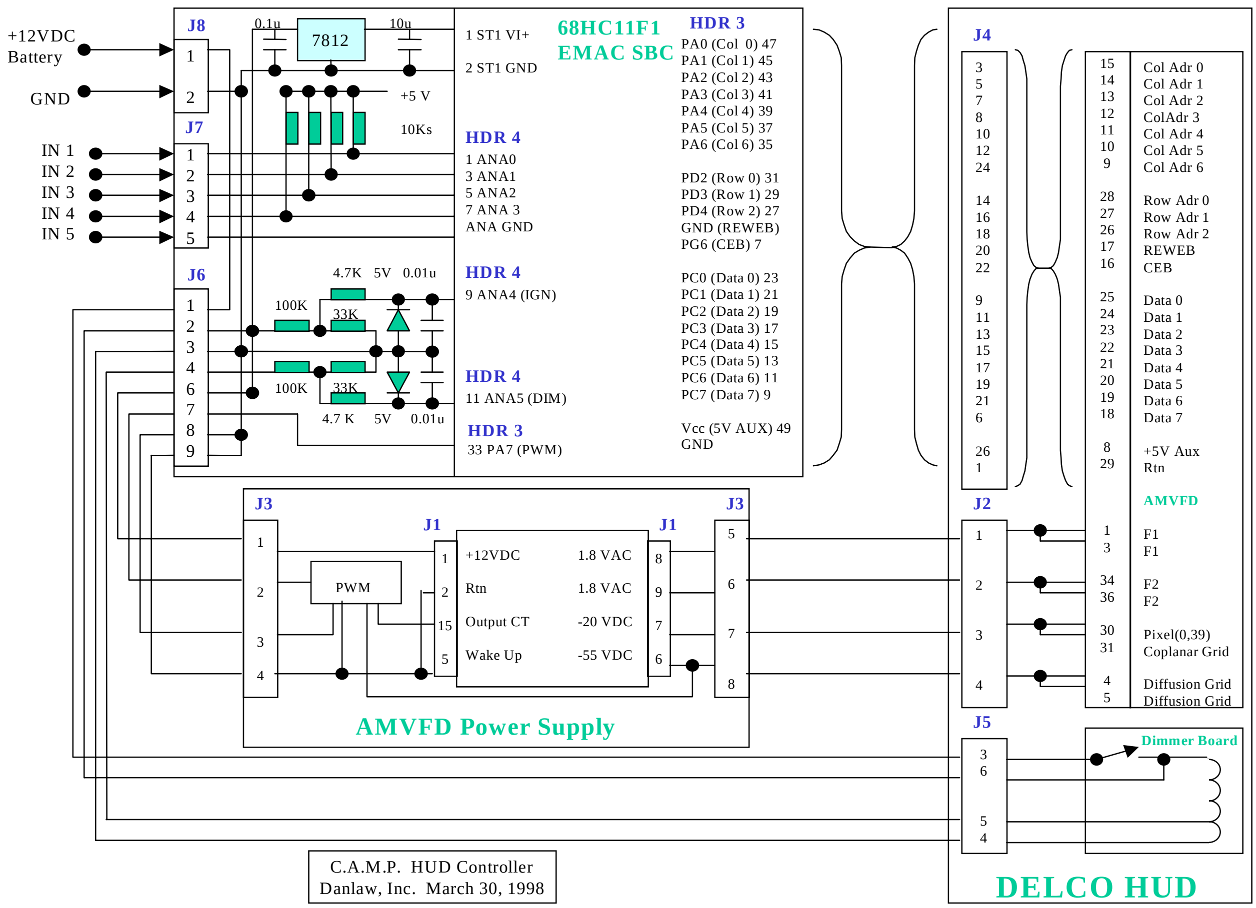
The non-speech and speech crash alerts were digitized "WAV" sound files on the computer that were played through the front car speakers at a 67.4 dBa sound level (averaging over left and right channels). The computer sound output was fed through the car's radio system by using a cassette adapter in the radio. The radio was turned on and set to cassette mode. The crash alert sound intensity (or loudness) was set using the radio volume controls. The non-speech and speech sounds selected were based on results from the auditory alert selection process, which is explained in detail in Appendix A19.

Haptic Crash Alert Modality Component

The brake pulse alert involved a brief (about 600 ms) vehicle jerk, involving a peak deceleration of 0.24 g's. (For the interested reader, a detailed description of the time-course of the brake pulse alert is shown in Appendix A16). This brake pulse profile was established during informal pilot testing with four drivers, since there were no relevant driver performance data available. In general, the goal of this pilot work was to allow the brake pulse to be clearly noticeable while avoiding, as much as possible, shifting the driver out of their driving position. Delphi Chassis Systems was contracted to supply the device that provided this example of a haptic crash alert. Delphi was required to modify the standard brake system on the SV so that the brakes could be pulsed from a computer to generate a deceleration rate between 0.15 to 0.30 g's for a duration between 0.1 to 2.0 seconds. All other brake functions were to operate as a standard brake system, and this device was required to not interfere with the normal operation of the vehicle brakes. The computer, using an analog output board, was to generate a 0 to 5-volt signal for the required brake pulse intensity and duration.

In response to these requirements, Delphi supplied and installed a brake modulation subsystem capable of applying up to a -0.30 g vehicle deceleration for speeds up to 60 mph on dry roads. A functional diagram of this subsystem is shown in Figure 3-30. This subsystem was controlled by a vehicle level controller by means of applying brake pressure to the front axle of the vehicle. The conventional base brake system and the ABS available on the car were not affected during manual braking by the driver. Any manual brake pedal application interrupted the add-on brake modulation and overrode any signal input to the modulation subsystem by the vehicle controller. The ABS and traction-control systems were not available (or operating) when the brake pulse was activated, which would be desirable from a production implementation perspective in order to address the activation of this alert on slippery surfaces. The CAMP computer interfaced to the embedded controller by 'System Command' and 'System Enable' signals. If the modulation subsystem detected a fault in its operation, a 'Fail Indicator' signal was sent to the CAMP Computer. To aid in problem-solving a fault, Delphi provided a software program. A separate serial interface was provided from the embedded controller for communication to the program. This program provided status information on the various internal parameters that could be used for trouble-shooting purposes.

Figure 3-29 Interconnections of HUD Components, HUD, HUD Power Supply, and the Controller



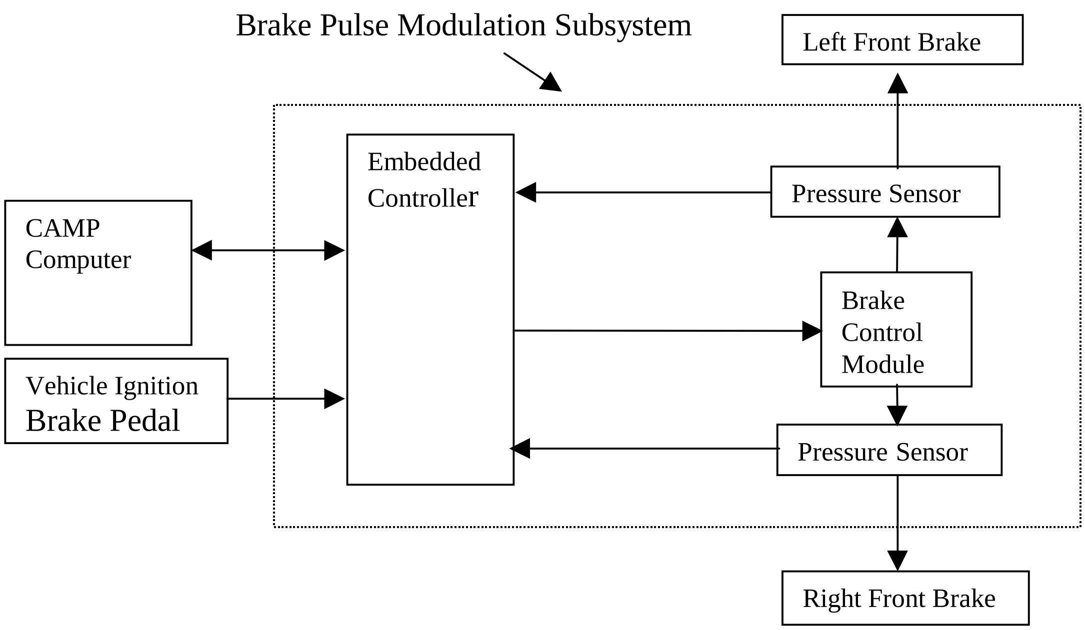


Figure 3-30 Brake Pulse Crash Alert Modulation Subsystem

3.7.6 Procedure and Design

Procedures Before and After Test Trials

After completing various pre-experiment forms and procedures (including the informed consent statement), subjects were escorted to the track. Drivers were then administered test instructions verbally (shown in Appendix A3), and asked to adjust the seat, steering wheel, and mirrors to their preferred position, and to fasten their shoulder harness and lap belt. It should be noted that subjects were instructed about the nature of the surrogate target, and more specifically, that this target was designed to allow low speed impacts. Subjects were also informed of the add-on passenger-side brake. Next, a sequence of test trials was conducted, which are described below. After the test trials were completed, subjects were escorted from the track, debriefed on the purpose of the study, and paid for their participation.

Test Phases / Driver Instructions

During the first phase of this study, drivers experienced trials in which the surrogate target was parked (or stationary). These types of test trials are referred to as *Alerted Stationary Trials*. Drivers were asked to approach the parked surrogate target at either 30 or 60 mph, and maintain a steady speed.

During the approach, a 1-stage, dual-modality crash alert was presented. Four separate crash alert types were evaluated, which are indicated below:

- Head-Up Display (HUD) + Non-Speech Tone
- High Head-Down Display (HHDD) + Non-Speech Tone
- High Head-Down Display (HHDD) + Speech
- High Head-Down Display (HHDD) + Brake Pulse

Drivers were instructed to brake immediately in response to the crash alert in order to avoid colliding with the artificial car. When the SV came to a complete stop, data collection was halted and the trial was ended.

Drivers were asked to make these braking responses under three different crash alert timing conditions, which are described shortly. During these alerted trials, drivers experienced 4 blocks of 6 trials each, with each block of trials dedicated to one crash alert type. The order of these crash alert type (or interface) blocks was appropriately counterbalanced across drivers. The six trials per block, were formed, by crossing the 2 approach speeds with the 3 crash alert timings. The approach speed changed every trial within a block, and the crash alert timing condition was randomized from trial-to-trial and appropriately counterbalanced across drivers.

After the Alerted Stationary Trials were completed, the second phase of the study began. In this phase, the driver was led to believe the test was over. An unexpected (surprise) braking event was then introduced in which the lead vehicle, traveling at 30 mph, suddenly braked at about a constant -0.38 g level of deceleration without brake lights. The crash alert type presented coincided with the type tested in the last block of test trials. This type of trial is referred to as the *Surprise Moving Trial.* In an attempt to create an inattentive driver prior to the unexpected braking event, the backseat experimenter engaged the driver in an active, naturalistic, 2-way conversation. This conversation typically occurred at the end of dialogue, which began with a brief informal debriefing discussion and ended with a “post-test” casual conversation. This conversation typically evolved around the driver’s summer vacations or job, as well as topics that evolved during the testing session. This surprise trial technique will be referred to as the “*Natural Conversation”* surprise technique.

The Surprise Moving Trial was then followed by two trials that were identical to the conditions of the Surprise Moving Trial, except that now drivers were fully aware that the lead vehicle would be braking. These types of trials will be referred to as *Follow-On Moving Trials*.

Crash Alert Timing Approach

For crash alert timing, an assumed total delay time (which included driver brake RT) and an assumed driver deceleration in response to the alert were input into straightforward, fundamental vehicle kinematic equations used for calculating the appropriate warning range to avoid a crash.

(These equations are described below.) These two critical, driver-behavior related inputs are now discussed in turn.

The assumed *total delay time* was the composite sum of three separate delay times, which are now described in the same time sequence in which they occurred. The *interface delay time* is defined as the time between when the crash alert criterion was violated and when the crash alert was presented to the driver. This delay is assumed to be 180 ms for all crash alert types examined except those including a brake pulse crash alert component. The brake pulse is assumed to onset after 410 ms, when the -0.10 g deceleration value was reached due to the brake pulse. (It should be noted that there was some variability associated with the time course of the brake pulse, which for the interested reader, is shown in Appendix A16). The *driver brake RT delay* is defined as the time between crash alert onset and when the driver triggered the brake switch. Based on discussions above, this delay was assumed to be 0.52 seconds for expected alerts, and 1.50 seconds for surprise alerts. The *brake system delay time* is defined as the time between braking onset and vehicle slowing, and is assumed to be 200 milliseconds. The assumed "*delay time range*" between crash alert criterion violation and vehicle braking is then the expected decrease in range during this total delay time, assuming the prevailing kinematic conditions (i.e., SV speed, POV deceleration) would continue during this total delay time. This delay time range, calculated as shown below, is added to a "*braking onset distance*" (described below) to calculate the desired warning range. In the equation below, "V" represents the current velocity (or speed), and dec_{SVM} and dec_{POVM} represents the current deceleration levels of the SV and POV, respectively. In this equation, the speed and deceleration variables should be expressed in feet/sec^2, and deceleration values are represented as negative values.

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

The assumed driver deceleration response in response to the crash alert was based on the required deceleration equation developed/modeled from CAMP Study 1 findings, which is shown below and discussed in detail in Appendix A20. This equation is subsequently referred to as the *CAMP Required Deceleration Parameter* (or *CAMP RDP equation*). In this equation, deceleration values are represented as negative values. This equation expressed in feet/sec^2 is as follows:

$$\text{Required Deceleration } (dec_{REQ}) = -5.308 + 0.685(dec_{POV}) + 2.570(\text{if POV moving}) - 0.086(\text{delta V})$$

(An alternative version of this equation predicts required deceleration in g's is shown in at the end of Appendix A20). (To remind the reader, the required deceleration measure was defined as the constant deceleration level required for the driver to avoid the crash at braking onset, assuming 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). In the above equations, the "delta V" predictor variable represents the speed difference between the SV and POV *projected* at braking onset and "POV dec." 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. Once again, in the above equation, the variables "delta V" and "dec_{POV}" should be expressed in feet/sec and feet/sec^2 respectively, which is consistent with the measurement units used in calculating delay time range above. These predicted required deceleration values are then converted to calculate a braking onset range or "braking onset range", using one of the three kinematic "case" equations described below. Given the assumed two 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 an alert 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 braking onset range is then calculated by inputting the predicted required deceleration value into the appropriate case equation below. Once again, in the equations below, the variables need to be expressed in common measurement units, which should be consistent with those used in calculating the delay time range and predicted required deceleration values above. Furthermore, deceleration values are represented as negative values. In the equations below, V_{SVP} and V_{POVP} represent the projected speeds of the SV and POV speed at SV braking onset, respectively. That is,

$$V_{SVP} = V_{SV} + (dec_{SV}(\text{Total Delay Time}))$$
$$V_{POVP} = V_{POV} + (dec_{POV}(\text{Total Delay Time}))$$

<u>Case 1</u>: POV Stationary →

$$\text{Braking Onset Range} = \frac{(V_{SVP})^2}{-2*(dec_{REQ})}$$

<u>Case 2</u>: POV Moving, contact when POV is moving →

$$\text{Braking Onset Range} = \frac{(V_{SVP} - V_{POVP})^2}{-2*(dec_{REQ} - dec_{POV})}$$

<u>Case 3</u>: POV Moving, contact when POV is stationary →

$$\text{Braking Onset Range} = \frac{(V_{SVP})^2}{-2*(dec_{REQ})} - \frac{(V_{POVP})^2}{-2*(dec_{POV})}$$

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

Warning Range = Delay Time Range + Braking Onset Range

This method of calculating a warning range will be referred to as the *CAMP Required Deceleration Parameter approach* (or the *RDP approach*). The reader should note that the RDP *approach* is different from the RDP *equation* described above. The RDP equation is but one of the input parameters used in the RDP approach to calculate a desired warning range. The required deceleration value (which is derived from the CAMP RDP equation) which is input into this Warning Range equation to calculate Braking Onset Range is distinctly different from commonly employed warning algorithms which assume a fixed driver deceleration response independent of driver speed and lead vehicle deceleration levels. Under the CAMP RDP equation, the assumed driver deceleration varies as a function of both the speed difference between the two vehicles (i.e., delta V) and lead vehicle deceleration levels. (For readers concerned with the details of implementing crash alert timing equations, it should be noted that the kinematic equations shown above were focused on closing scenarios encountered in these interface experiments. Additional logic and equations, which are not shown above, were also implemented in these experiments so that inappropriate alerts did not occur in normal, non-braking situations (e.g., when the range between the vehicles is increasing). 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 to handle normal, non-braking driving conditions and to issue alerts in unusual circumstances with crash alert timing that is equivalent to that described here.)

Drivers were tested with three different crash alert timing approaches. The first approach used the RDP crash alert timing approach described above. The remaining two approaches assumed the driver would brake in response to the crash alert harder than that predicted by the RDP crash alert timing, or put in another way, drivers would brake harder than what was observed/modeled in CAMP Study 1 without a crash alert. Hence, the RDP crash alert timing provided the most conservative timing assumption, or put in another way, the earliest, farthest crash alert timing assumption examined. The second crash alert timing approach assumed the driver decelerated in response to the crash alert with an additional 0.05 g's relative to the RDP crash alert timing approach, and is subsequently referred to as the "RDP + 0.05 g" crash alert timing approach. The third, and most aggressive (latest, closest) crash alert timing approach, assumed the driver decelerated in response to the crash alert with an additional 0.10 g's relative to the RDP crash alert timing approach, and is subsequently referred to as the "RDP + 0.10 g" crash alert timing approach. In each of these three crash alert timing approaches, if the predicted warning range was larger than the observed warning range, the crash alert criterion was violated and the crash alert was presented.

"Bail-out" visual markers were placed on the right-center portion of the driving lane to provide the front seat, passenger-side experimenter information on when to take over braking using the add-on brake. Separate markers were positioned for each of the three different approach speeds examined (30, 45, and 60 mph). The test drivers were to begin braking at the point the vehicle occluded the visual marker. The distances for these markers were formed by having a driver approach a test reflector target at 5 mph above the target approach speed, while the test driver used the add-on brake to brake to the bail-out visual marker. Repeated trials were performed with each of the test drivers, and the longest braking distance found at each of the three speeds were using to create the visual marker distances.

The visual alerts were presented as long as the crash alert timing criterion was violated, whereas both the auditory and brake pulse alerts played out for a maximum of one entire cycle. In the event that the "bail-out" auditory alert for the experiment was triggered, the "bail-out" alert interrupted the non-speech tone intended for the driver. The "bail-out" auditory alert for the front seat, passenger-side experimenter was also triggered based on the RDP crash alert timing approach, with assumed inputs of a 0.52 second driver (test driver) brake RT, and an assumed constant deceleration in response to the crash alert of -0.55 g's. The "bail-out" sound, which was distinct from the non-speech tone employed, signaled to the experimenter to take over braking using the add-on brake. A black cardboard visual barrier was placed between the driver and the front seat experimenter which prevented the driver from anticipating (or being distracted by) the foot (braking) behavior of the experimenter, and allowed the experimenter to discretely let their foot hover over the add-on brake during a test trial.

Independent Variables Examined

For the Alerted Stationary Trials, the within-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse), crash-alert timing (RDP, RDP + 0.05 g, and RDP + 0.10 g), and (approach) speed (30 and 60 mph), and the between-subjects variables analyzed were age (younger, middle-aged, or older) and gender (male or female).

For the Surprise Moving Trial and the Follow-On Moving Trials, the between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, or HHDD + Brake Pulse) and age (younger, middle-aged, or older).

Objective (or Performance) Measures Examined

Various performance measures were analyzed. The variable definitions, and the point in time during the braking maneuver in which the performance measures were analyzed (at POV braking onset, at SV braking onset, throughout the braking, end of the braking maneuver) are identical to that used in Study 1, with the exception of one new measure, driver's brake reaction time (RT). This measure is defined as the time between crash alert onset and the driver contacting the brake (i.e., triggering the brake switch) in response to the alert.

Subjective Measures / Questionnaire Data

Immediately after each braking trial, drivers were asked to judge the appropriateness of the FCW system crash alert timing using the 7-point scale ranging from “much too early” to “much too late”, which is shown in the opening paragraphs of the “Study 2 Experimental Methodology and Approach” section. (In this study, drivers were also asked how well the urgency level suggested by the alert matched the timing of the alert on a scale ranging from “much too low” to “much too high”, with a “just right” mid-point. This question proved somewhat difficult to construct in a meaningful way for drivers, although these results were extremely consistent with the pattern of crash alert timing results reported below. Hence, the results from this “urgency level” question will not be discussed further.)

These timing appropriateness ratings were analyzed for each phase of the study using the same independent variables and analysis approach that was used to analyze the driver performance measures.

Several questionnaires were administered throughout the study. During the first phase of Alerted Stationary Trials, drivers rated each crash alert type after experiencing the block of 6 trials with a given crash alert type. This “*alert modality appropriateness*” questionnaire involved the driver rating each modality of the crash alert type just experienced on various attributes. Excerpts of this questionnaire are shown in Appendix A4. For the visual alerts, drivers rated the intensity, size, color, and location of the display. For the auditory (non-speech and speech) alerts, drivers rated the loudness and duration of the alert. In addition, drivers were asked whether the radio should be muted during the alert. For the brake pulse alert, drivers rated the strength of the vehicle jerk and the duration of the alert.

At the end of the study, drivers were asked to fill out three separate questionnaires. In the first questionnaire, drivers were asked to rate each of the 1-stage, dual-modality crash alert types experienced on 14 different statements. This “*crash alert appropriateness*” questionnaire is shown in Appendix A5. These statements involved the driver rating each of the four crash alert types on the 14 statements, in the order shown below. These statements were associated with “overall” ratings, crash alert noticeability, confusion, attention-getting properties, startle, interference with driving, annoyance, harmony, association with danger, and purchase interest. Each of these statements was rated on a 7-point scale ranging from Strongly Disagree to Strongly Agree.

Crash Alert Appropriateness Statement

1. This is a good method for presenting crash alerts to drivers.
2. This method would be clearly noticeable in the car.
3. This method would NOT be confused with other events happening either inside or outside the car.
4. This method would get my attention immediately if I was distracted and not concentrating on the driving task.
5. This method would NOT startle me, that is, cause me to blink, jump, or make a rapid reflex-like movement.
6. This method would NOT interfere with my ability to make a quick and accurate decision about the safest driving action to take (brake, steer, brake and steer, do nothing).
7. This method would NOT interfere with my ability to perform a quick and accurate emergency driving action.
8. This method would NOT annoy me if the alert came on once a week in a situation where no driving action was required.
9. This method would NOT annoy me if the alert came on once a day in a situation where no driving action was required.
10. This method would NOT appear out of place in a car or truck.
11. This method would clearly tell me that I am in danger and need to react immediately.
12. This method of presenting crash alert information has great potential for preventing me from getting in a rear-end accident.
13. This method of presenting crash alert information would get my attention without being overly annoying.
14. If cost were not an issue, I would be likely to purchase this type of crash alert feature when I purchased a vehicle.

In the second questionnaire completed at the end of the test, drivers were asked to create their own interface. This "*build an interface*" questionnaire is shown in Appendix A6. Drivers were first asked to build a 1-stage crash alert, and then asked to build a 2-stage crash alert.

In the third and final questionnaire, drivers were asked to name the FCW system. This "*name the system*" questionnaire is shown in Appendix A7. Drivers were first asked to name the system in an open-ended fashion, and then asked to rank order their top three name choices from the following set of proposed system names:

<u>Proposed System Names</u>

- Forward Collision Warning System
- Forward Crash Warning System
- Forward Accident Warning System
- Rear-end Collision Warning System
- Rear-end Crash Warning System
- Rear-end Accident Warning System
- Front-end Collision Warning System
- Front-end Crash Warning System
- Front-end Accident Warning System

3.7.7 Results and Discussion

Overview of Statistical Analysis Approach for Objective Measures

For the analysis of the objective (or performance) measures, a factorial Analysis of Variance (ANOVA) was performed for each relevant driver performance measure (dependent on whether the lead vehicle was moving or stationary) shown previously in Table 3-1. Data from the Alerted Stationary Trials, Surprise Moving Trial and Follow-On Moving Trials were analyzed separately during the statistical analysis. The criterion set for statistical significance was $p<0.01$ during the analysis of the Alerted Stationary Trials (Study 2), due to the large number of statistical tests carried out (which increases the probability of spuriously significant results (Hays, 1981). For the analysis of the Surprise Moving Trial (in Study 2 and Study 3) and the Follow-On Moving Trials data, the criterion set for statistical significance was $p<0.05$. Unless otherwise noted, all statistically significant results indicated met (and often exceeded) these adopted criterion.

Objective (Or Performance) Measures

Alerted Stationary Trials

The within-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse), crash alert timing (RDP, RDP + 0.05 g, and RDP + 0.10 g), and (approach) speed (30 and 60 mph), and the between-subjects variables analyzed were age (younger, middle-aged, or older) and gender (male or female). Results indicated main effects of age on the brake RT and TTC measures.

For the younger, middle-aged, and older groups, mean brake RTs were 491, 533, and 627 ms, respectively, and mean TTC values were 2.9, 2.7, and 2.8 seconds, respectively. There were also relatively robust main effects of crash alert type, crash alert timing, and speed. These effects found for various performance measures are shown in Table 3-14, Table 3-15 and Table 3-16 respectively. These effects will be discussed to help the reader get oriented to the large volume of data analyzed, however, it should be stressed that many of these main effects need to be interpreted in terms of higher-order interactions, which are discussed below.

Table 3-14 Significant Main Effects of Crash Alert Type on Various Measures During Alerted Stationary Trials (Study 2)

	At SV Braking Onset			
Crash Alert Type Condition	**Mean Brake RTs**	**Mean Current Dec. (g)**	**Mean Req. Dec. (g)**	**Mean TTC (sec)**
HUD + Non-Speech	502	-0.03	-0.42	2.8
HHDD + Non-Speech	509	-0.03	-0.42	2.8
HHDD + Speech	573	-0.03	-0.44	2.7
HHDD + Brake Pulse	617	-0.07	-0.39	2.9

Table 3-15 Significant Main Effects of Crash Alert Timing on Various Measures During Alerted Stationary Trials (Study 2)

	At Braking Onset				Throughout Braking			End of Braking
Crash Alert Timing Condition	**Mean Brake RTs (sec)**	**Mean Range (feet)**	**Mean TTC (sec)**	**Mean Req. Dec. (g)**	**Mean Actual Dec.**	**Mean Peak Dec. (g)**	**Mean Min. TTC (sec)**	**Mean Range (feet)**
RDP	575	213	3.1	-0.37	-0.52	-0.70	1.8	40
RDP + 0.05 g	547	193	2.8	-0.42	-0.56	-0.76	1.5	30
RDP + 0.10 g	529	173	2.5	-0.47	-0.59	-0.82	1.3	22

Table 3-16 Significant Main Effects of Speed on Various Measures During Alerted Stationary Trials (Study 2)

	At Braking Onset				Throughout Braking			End of Braking
Target Speed Cond.	**Mean Speed**	**Mean Range (feet**	**Mean TTC (sec)**	**Mean Req. Dec. (g)**	**Mean Actual Dec.**	**Mean Peak Dec. (g)**	**Mean Min. TTC (sec)**	**Mean Range (feet)**
30 mph	30.4	104	2.3	-0.36	-0.52	-0.71	1.3	19
60 mph	59.3	282	3.2	-0.47	-0.59	-0.81	1.8	42

The brake RT results shown in Table 3-14 are also shown in the left-hand portion of Figure 3-31. Follow-up planned comparison tests indicated faster RTs in the HUD + Non-Speech and HHDD + Non-Speech conditions relative to both the HHDD + Speech and HHDD + Brake Pulse conditions. In addition, these follow-up tests indicated faster RTs in the HHDD + Speech relative to HHDD + Brake Pulse conditions. Hence, the rank ordering of these brake RT results were as follows:

(HUD + Non-Speech=HHDD + Non-Speech) < HHDD + Speech < HHDD + Brake Pulse

The results from the remainder of the measures shown in Table 3-14 indicate a trade-off between brake RT and the effect of the HHDD + Brake Pulse cue slowing the vehicle during the “total delay time” interval discussed earlier (which includes driver RT). The consequence of this slowing can be mainly seen in the pattern of results for the mean current deceleration measure at SV braking onset, which indicates an additional -0.04 g of deceleration for the HHDD + Brake Pulse condition at SV braking onset relative to the remaining crash alert types examined. If braking was the appropriate response to an alert, this data would suggest that trade-off may actually favor the HHDD + Brake Pulse condition (relative to the other three crash alert type conditions), since at braking onset, the driver is in a more conservative kinematic scenario (lower required deceleration and higher TTC values).

The main effects of crash alert timing shown in Table 3-15 are very systematic and straightforward to interpret. These results indicate that as the crash alert timing became more aggressive, the driver was closer to the parked surrogate target at braking onset, the driver exhibited more aggressive braking (and minimum TTC) behavior, and the driver ended up closer to the parked vehicle. In addition, these results indicate that drivers' brake RTs decreased slightly (perhaps due to an increase in perceived threat) as the crash alert timing became more aggressive. It should be noted that the 0.05 g steps employed to form the three crash alert timing conditions tested are validated in Table 3-15 for the required deceleration measure.

The main effects of speed shown in Table 3-16 are also systematic and straightforward to interpret. These results indicate that in the 60 mph relative to 30 mph condition, the driver exhibited more aggressive braking behavior (although in the context of more conservative minimum TTC values), and the driver was farther away from the parked vehicle at both braking onset and at the end of braking.

The remainder of the discussion in this section will focus on interpreting the various higher-order interactions which were observed for various measures obtained at SV braking onset, throughout braking, and at the end of braking. Overall, these higher-order interactions were generally small in magnitude, of little practical significance, and not robust across related performance measures. However, a brief explanation of each of these interactions is provided below for the sake of completeness for the interested reader. (The non-interested reader is encouraged to proceed to the next section.) Also, in the event that a higher-order interaction (e.g., 4-way) encompasses a lower higher-order interaction (e.g., 2-way), a description of the higher-order interaction is provided (which is the context in which the “lower” higher-order interaction should be interpreted).

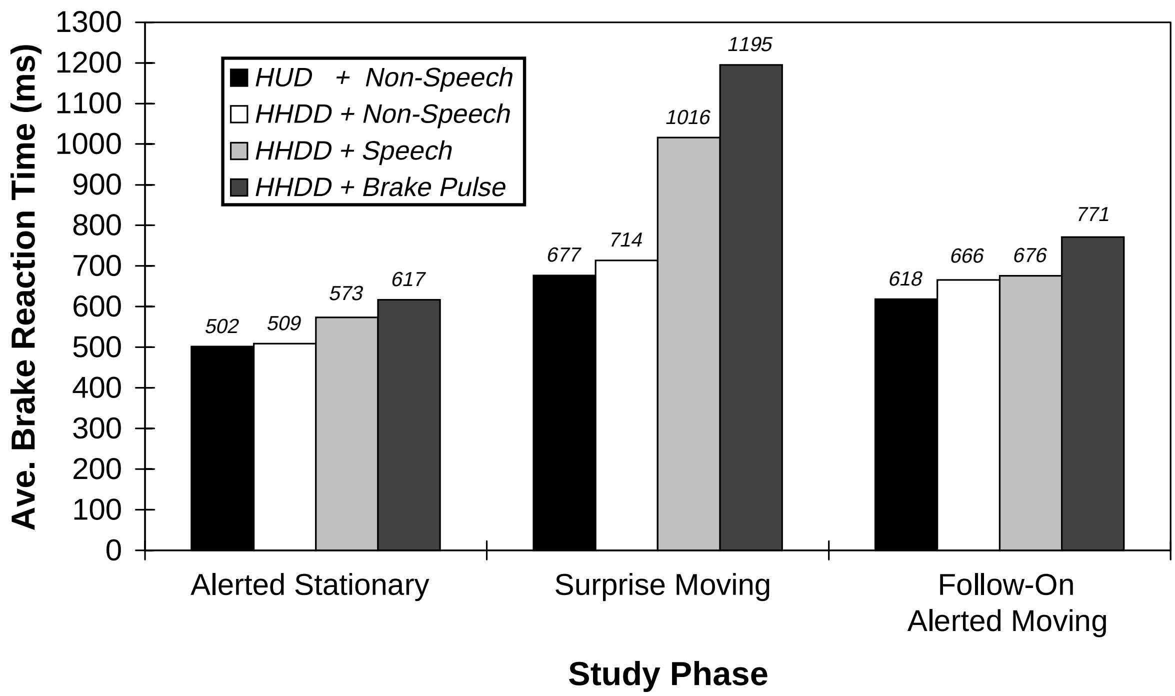


Figure 3-31 Average Brake Reaction Time as a Function of Study Phase and Crash Alert Type (Study 2)

For the brake RT measure, results indicated a Crash Alert Type x Speed interaction, and a (4-way) Age x Gender x Crash Alert Type x Speed interaction. With respect to the former interaction, in the 30 mph condition, brake RTs in the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse conditions were 509, 514, 531, and 616 ms, respectively. The corresponding means for the 60 mph condition were 502, 508, 595, and 640 ms, respectively. Hence, the brake RT advantage mentioned above for the HUD + Non-Speech and HHDD + Non-Speech conditions relative to the HHDD + Speech and HHDD + Brake Pulse increased with the higher speed approach. Results from the 4-way interaction mentioned above indicated that the intermediate (i.e., second place) mean brake RT position for the HHDD + Non-Speech condition described above was far more stable in the 60 mph condition. In the 30 mph condition, the HHDD + Non-Speech brake RTs were generally quite similar to those found in the HUD + Non-Speech and HHDD + Non-Speech conditions.

For the SV deceleration at braking onset measure, results indicated an Age x Crash Alert Type, Age x Gender x Crash Alert Type, and a Crash Alert Type x Crash Alert Timing x Speed interaction. Results for the Age x Gender x Crash Alert Type interaction for the SV deceleration at braking onset measure indicated that this measure was very stable across all cell combinations of these three variables (ranging between -0.03 and -0.04 g's), except in the HHDD + Brake Pulse crash alert type condition. For this latter crash alert type, across all Age x Gender cell combinations, the SV deceleration at braking onset ranged between -0.04 and -0.12 g's. For male drivers in the HHDD + Brake Pulse crash alert type condition, the mean SV deceleration at braking onset decreased as age increased (which is consistent with the main age effect observed for brake RTs, since younger drivers may have been more likely to interrupt the completion of the brake pulse "cycle" relative to older drivers) . In contrast, for female drivers in this crash alert condition, the mean SV deceleration at braking onset was highest for middle-aged females. Results for the Crash Alert Type x Crash Alert Timing x Speed interaction for the SV deceleration at braking onset measure indicated that this measure was very stable across all cell combinations of these three variables (ranging between -0.03 and -0.04 g's), except once again for the HHDD + Brake Pulse crash alert type condition. For this latter crash alert type, across all Crash Alert Timing x Speed cell combinations, the SV deceleration at braking onset ranged between -0.05 and -0.09 g's. In the 30 mph condition for the HHDD + Brake Pulse crash alert type condition, the mean SV deceleration at braking onset *decreased* as the crash alert timing became more aggressive. In contrast, in the 60 mph condition in this crash alert condition, the mean SV deceleration at braking onset *increased* as the crash alert timing became more aggressive.

For the SV speed at SV braking onset measure, results indicated Gender x Crash Alert Type x Speed, Age x Gender, Crash Alert Type x Crash Alert Timing, and Age x Gender x Crash Alert Type x Speed interactions. Results for the Gender x Crash Alert Type x Speed interaction for this measure, indicated, that this measure was very stable across all cell combinations. Of these three variables (within 1.4 mph) for 3 out of the 4 crash alert type conditions at both speeds across all Gender x Speed condition cell combinations. However, in the 30 mph condition with the HUD + Non-Speech crash alert type, the mean SV speed at braking onset was slightly higher (2.7 mph) for female relative to male drivers. In addition, in the 60 mph condition with the HHDD + Speech crash alert type, the mean SV speed at braking onset was slightly higher (2.4 mph) for female relative to male drivers. Results for the Age x Gender x Crash Alert Type x Speed interaction for the SV speed at braking onset measure appeared to be due to a relatively unstable pattern of mean speeds across crash alert timing conditions for the middle-aged male and younger female groups.

For the range at SV braking onset measure, results indicated Crash Alert Timing x Speed and Age x Crash Alert Type x Crash Alert Timing x Speed interactions. With respect to the former interaction, in the 30 mph condition, the range at braking onset for RDP, RDP + 0.05 g, and RDP + 0.10 g conditions were 117, 104, and 91 feet, respectively. Corresponding means for the 60 mph condition were 309, 282, and 256 feet, respectively. Hence, the difference in ranges between the 30 mph and 60 mph conditions decreased as the crash alert timing became more aggressive. The 4-way interaction involving this measure indicated a general decrease in range as the crash alert timing became more aggressive for the various Age x Crash Alert Type x Speed cell combinations, with the exception of the middle-aged x HHDD + Brake Pulse x 60 mph cell combination. For this latter combination of conditions, the mean range at SV braking onset was higher in the RDP + 0.05 g crash alert timing condition relative to either the RDP or RDP + 0.10 g timing conditions.

With respect to the required deceleration and TTC measures (both measured at braking onset), there was an Age x Gender interaction for the former measure, and a (4-way) Age x Gender x

Crash Alert Type x Speed interaction for both measures. For this latter interaction, for both the required deceleration and TTC measures, the crash alert type differences shown in Table 3-14 for these measures were relative stable for the various Age x Gender cell combinations in the 30 mph condition (with the exception of the younger female group). In the 60 mph condition, this pattern of crash alert type differences was less stable, occurring for 2 to 3 of the 6 Age x Gender cell combinations.

For the actual deceleration measure (which is an alternative way of expressing braking distance), it is worth noting there were no higher-order interactions. Based on the main effects of only crash alert timing and speed reported above for this measure, this indicates that neither age, gender, nor the crash alert types played any role in affecting observed braking distances. This indirectly suggests that once drivers (regardless of age or gender) received an alert (regardless of the crash alert), braking occurred in a relatively systematic fashion based on the prevailing kinematic conditions (the latter of which was determined by crash alert timing condition).

For the peak deceleration measure, results indicated a Crash Alert Timing x Speed interaction. In the 30 mph condition, the mean peak deceleration values for the RDP, RDP + 0.05 g, and RDP + 0.10 g conditions were -0.64, -0.72, and -0.78 g's, respectively. In the 60-mph condition, the corresponding mean values were -0.77, -0.81, and -0.86, respectively. Hence, the difference between peak deceleration values across speed conditions was highest in the RDP crash alert timing condition.

For the minimum TTC measure, there was a (5-way) Age x Gender x Crash Alert Type x Crash Alert Timing x Speed interaction. This interaction indicated a general decrease in mean minimum TTC as the crash alert timing became more aggressive for the various 48 Age x Gender x Crash Alert Type x Speed cell combinations. This pattern is much more stable in the 30 mph condition (particularly for males) relatively to the 60 mph condition.

For the minimum range measure, there was also a (5-way) Age x Gender x Crash Alert Type x Crash Alert Timing x Speed interaction. This interaction indicated a general decrease in range as the crash alert timing became more aggressive for the 48 various Age x Gender x Crash Alert Type x Speed cell combinations, with the exception of the Middle-Age x Male x HHDD + Brake Pulse x 60 mph speed cell combination and the 4 Younger x Female x 60 mph speed condition cell combinations (1 combination for each crash alert type).

Surprise Moving Trial

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, or HHDD + Brake Pulse) and age (younger, middle-aged, or older).). It should be noted that there were no Surprise Moving Trials in which the passenger-side experimenter intervened to assist the driver in coming to a stop.

Results indicated a main effect of crash alert type on brake RTs, which is shown in the middle portion of Figure 3-31. The trend of these RTs are identical to those found across crash alert types during Alerted Stationary Trials, and provide converging evidence for the effect of crash alert type on RTs across alerted and surprise braking event conditions. Follow-up tests indicated significantly faster brake RTs in the HUD + Non-Speech relative to HHDD + Brake Pulse conditions, and significantly faster brake RTs in the HHDD + Non-Speech relative to HHDD + Brake Pulse conditions. It is important to note that the differences in brake RTs observed across crash alert types during Alerted Stationary Trials are now exaggerated and substantially larger in the Surprise Moving Trial data (e.g., the fastest crash alert condition is nearly twice as fast as the slowest condition). Figure 3-32 provides the brake RT distribution for all drivers during these Surprise Moving Trials. It is worth noting that only one subject yielded a brake RT higher than the 1.5 second brake RT assumed for crash alert timing purposes.

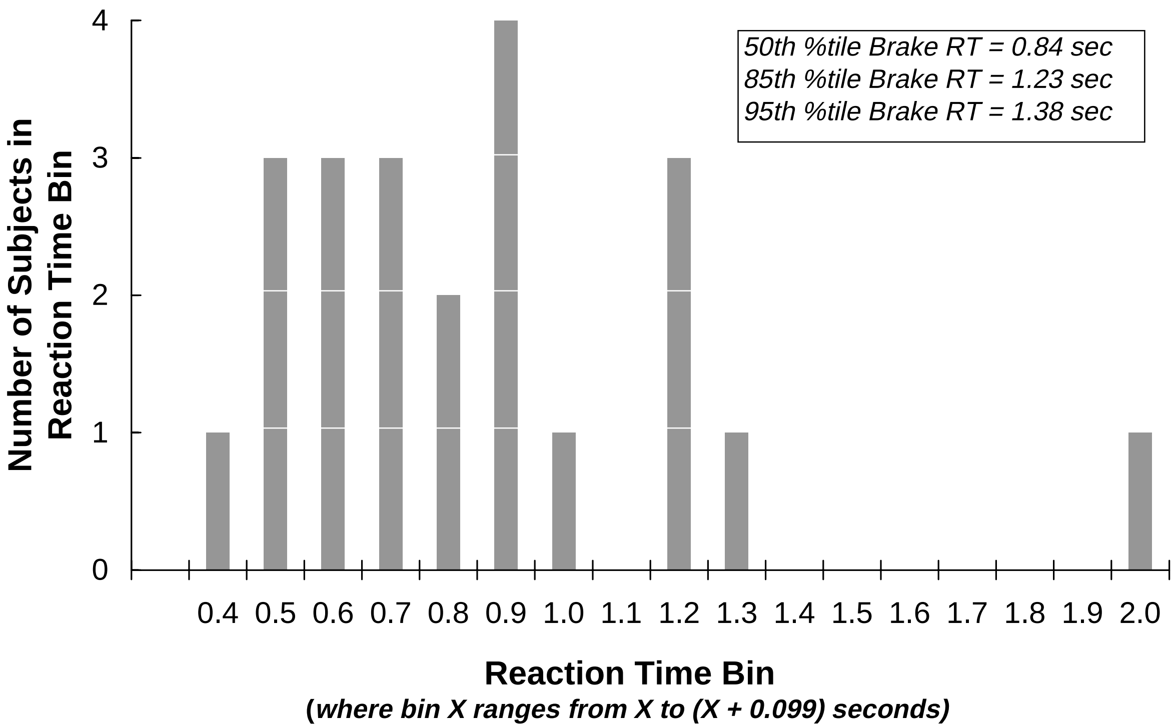


Figure 3-32 Brake Reaction Time Distribution During Surprise Moving Trials (Study 2)

Results also indicated a significant effect of crash alert type on POV speed at SV braking onset. The mean POV speed at SV braking onset for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse conditions were 24.5, 25.6, 20.9, and 19.4 mph, respectively. These differences are likely to be due in large part to the RT differences cited above, since increases in RTs result in a longer time during which the POV is decelerating (and hence, reducing speed) at a constant rate.

Results also indicated a significant effect of crash alert type on POV deceleration at braking onset, and a significant Age x Crash Alert Type interaction on this measure. For younger drivers, the mean POV deceleration at SV braking onset for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse conditions were 0.39, 0.38, 0.41, and 0.39 g's, respectively. For the middle-age drivers, the corresponding mean values were 0.37, 0.39, 0.40, and 0.48 g's, respectively. For the older drivers, the corresponding mean values were 0.39, 0.34, 0.56, and 0.39 g's, respectively. The mean decelerations which fall out of the 0.37-0.41 range are likely due to contributions of trials in which the POV driver braked the lead vehicle due to a brake controller failure in the POV.

In summary, results from the Surprise Moving Trials indicate that the fastest brake reactions times occurred in the HUD + Non-Speech and HHDD + Non-Speech conditions (as was found during the Alerted Stationary Trials), and that the RT advantage of these conditions over the HHDD + Speech and HHDD + Brake Pulse crash alert types was increased substantially in the Surprise Moving Trials (relative to the Alerted Stationary Trials). For reference purposes, Table 3-17 provides a list of various percentile values for key variables, nearly all of which were not involved in any of the significance effects discussed above.

Follow-On Moving Trials

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, or HHDD + Brake Pulse) and age (younger, middle-aged, or older). Results indicated no statistically significant effects on the brake RT measure. For comparison purposes, results found for the brake RT measure across the various crash alert types are shown in the rightmost portion of Figure 3-31. These results indicate essentially the same (albeit statistically non-significant) trend in the means as observed during both the Alerted Stationary Trials and Surprise Moving Trial study phases, which provides strong evidence that the observed trend is very robust. One possible reason for the lack of statistically significant effects during these Follow-On Moving Trials is difficulties reported by the experimenter in getting the subjects focused on performing during these trials which were experienced immediately after the Surprise Moving Trial.

However, results did indicate a significant effect of crash alert type on SV deceleration at braking onset, POV speed at braking onset, and TTC-Case 1 at SV braking onset. These effects are shown in Table 3-18. As in the Surprise Moving Trial phase, these differences may be due in part to the (statistically non-significant) brake RT differences observed across crash alert types discussed above. Results also indicated a significant effect of age on POV speed at SV braking onset. The mean POV speed at SV braking onset for the young, middle-aged, and older groups were 26.0, 25.7, and 22.2 mph, respectively.

Table 3-17 Percentile Values for Key Driver Performance Measures During Surprise Moving Trials for Study 2 (Across All Combinations of Age, Gender, and Crash Alert Type)

Time During Which Variable was Measured	Dependent Measure (unit)	15th %tile Value	50th %tile Value	85th %tile Value
At POV Braking Onset	Time Headway (sec)	1.0	1.5	1.9
At SV Braking Onset	Brake Reaction Time (sec)	0.59	0.84	1.23
	Required Deceleration (g)	-0.28	-0.33	-0.42
Throughout Braking	Braking Distance (feet)	75	94	105
	Actual Deceleration (g)	-0.35	-0.42	-0.47
	Peak Deceleration (g)	-0.53	-0.60	-0.77
	Minimum Headway (sec)	0.6	1.2	1.6
	Minimum Range (feet)	5	17	28

Table 3-18 Significant Main Effects of Crash Alert Type on Various Measures During Follow-On Moving Trials (Study 2)

	At SV Braking Onset		
Crash Alert Type Condition	**Mean Current Dec. (g)**	**Mean POV Speed (mph)**	**Mean TTC / Case 1 (sec)**
HUD + Non-Speech	-0.02	25.9	8.6
HHDD + Non-Speech	-0.03	25.6	7.0
HHDD + Speech	-0.03	23.7	7.0
HHDD + Brake Pulse	-0.05	23.3	5.3

Subjective Measures / Questionnaire Data

Crash Alert Timing Ratings

<u>Alerted Stationary Trials</u>

The within-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse), crash alert timing (RDP, RDP + 0.05 g, and RDP + 0.10 g), and (approach) speed (30 and 60 mph), and the between-subjects variables analyzed were age (younger, middle-aged, or older) and gender (male or female). Results indicated main effects of crash alert timing and speed, as well as a Crash Alert Timing x Speed interaction. In the 30 mph condition, mean crash alert timing ratings for the RDP, RDP + 0.05 g, and RDP + 0.10 g crash alert timings were 4.1, 4.4, and 4.8, respectively. Corresponding mean ratings in the 60 mph condition were 3.6, 4.3, and 4.7, respectively. Hence, the ratings increased (i.e., became "later") as the crash alert timing became more aggressive, and the difference in timing ratings between the two speed conditions examined appear to be limited to the RDP crash alert timing condition. Overall, the mean crash alert timing ratings for the RDP, RDP + 0.05 g, and RDP + 0.10 g conditions were 3.9, 4.4, and 4.7, respectively. These results indicate that under these well-controlled Alerted Stationary Trials, drivers clearly perceived the differences between the three crash alert timing approaches evaluated.

Results also indicated a main effect of age, as well as a marginally significant ($p<0.02$) main effect of Crash Alert Type. Overall, the mean crash alert timing ratings for younger, middle-aged, and older groups were 4.6, 4.4, and 4.0, respectively. Follow-up tests indicated a difference between the ratings for the younger versus older groups, while the difference between the middle-aged and older groups approached significance ($p<0.05$). Overall, the mean timing ratings for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse conditions were 4.4, 4.3, 4.5, and 4.1, respectively. Follow-up tests indicated a difference only between the ratings in the HHDD + Speech and HHDD + Brake Pulse conditions.

A more insightful look at these crash alert timing data is provided in Figure 3-33. The histogram provided shows the percent of responses at each point along the crash rating scale as a function of crash alert timing. (For each crash alert timing, across all drivers, 192 total ratings were made). This figure averages over the independent variables crash alert type, speed, age, and gender, since overall, the effects reported above are modest in size (across all Crash Alert Type x Speed x Age x Gender combinations, the mean ratings ranged from 3.6-5.1 on a 7-point scale).

As can be seen in Figure 3-33, the largest percent (about half) of responses for the RDP and RDP + 0.05 crash alert timings occurred at the "just right" (i.e., "4") point along the rating scale, whereas the largest percent of responses for the RDP + 0.10 g crash alert timing occurred at the "slightly late" (i.e., "5") point along the rating scale. It should be noted that the percent of "much too early", "moderately early", "moderately late", and "much too late" responses are extremely low (<5%) across nearly all crash alert timing conditions. The one notable exception to this trend is that over 10% of drivers rated the RDP + 0.10 g crash alert timing as "moderately late."

Overall, these data clearly suggest that the range of timing approaches employed in this study appear to bracket driver preferences for crash alert timing. If the goal was to get a distribution of responses that were symmetrically distributed around the "just right" midpoint of the scale, it appears timing somewhere between the RDP and RDP + 0.05 g timing should be employed. Furthermore, the trade-offs between a crash alert timing approach which is slightly skewed toward early versus skewed toward late in terms of subjective ratings (i.e., RDP versus RDP + 0.05 g) is not entirely straightforward.

Surprise Moving Trial

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, or HHDD + Brake Pulse) and age (younger, middle-aged, or older). Recall, in this study phase, that the RDP crash alert timing was used. Results indicated no statistically significant effects, with an overall rating of 4.2 (closest to "just right"). A histogram provided in Figure 3-34, shows the percent of timing responses at each point along the crash rating scale. Across all drivers, 24 total rating were made. This data indicates that 83% of the timing responses were "just right", and 8% of the timing responses were either "slightly early" or "slightly late."

Follow-On Moving Trials

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, or HHDD + Brake Pulse) and age (younger, middle-aged, or older). Once again, in this study phase, the RDP crash alert timing was used. Results indicated no statistically significant effects, with an overall rating of 4.0 (closest to "just right").

Summary of Crash Alert Timing Ratings Findings

In summary, the crash alert timing ratings from the Alerted Stationary, Surprise Moving, and Follow-On Moving Trials provide strong evidence that the crash alert timing approach directly derived/modeled from the CAMP Study 1 findings (i.e., the RDP crash alert timing) does an excellent job from a driver preference perspective under a wide range of driver expectancy conditions. As is best shown in Figure 3-33, assuming "slightly early", "just right", and "slightly late" ratings would be acceptable to drivers using the RDP algorithm, the combined ratings of "moderately early" and "much too early" amounted to only 6% of all ratings using this crash alert timing, and "moderately late" ratings amounted to only 3% of all ratings using this timing (there were no "much too late" ratings with this timing). Consequently, in the remaining CAMP studies, the RDP crash alert timing approach (the most conservative tested in this study) was employed.

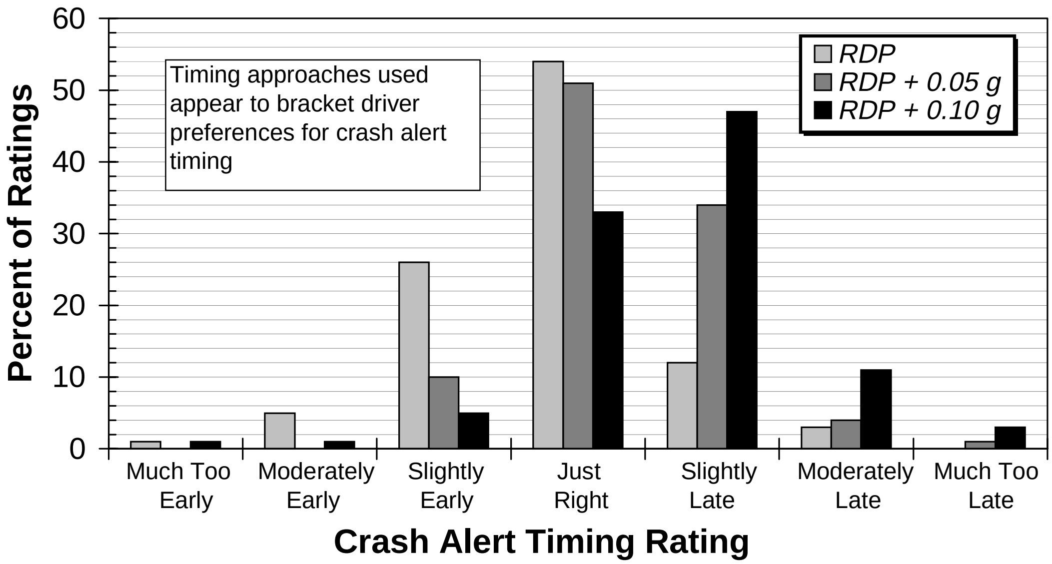


Figure 3-33 Histogram of Subjective Crash Alert Timing Ratings as a Function of Crash Alert Timing Approach During Alerted Stationary Trials (Study 2)

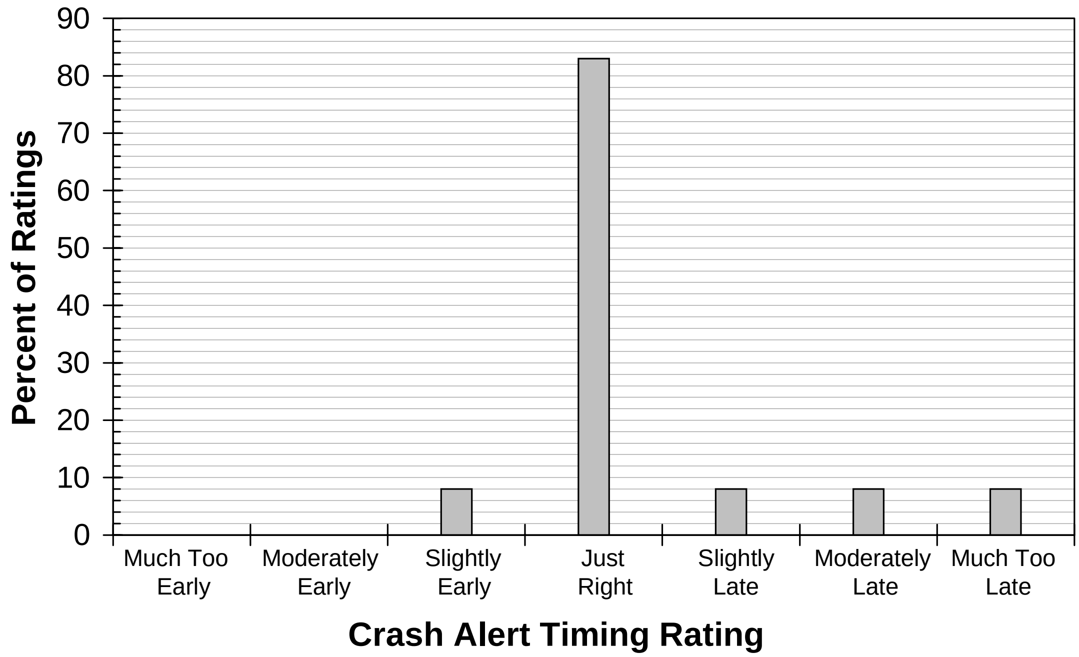


Figure 3-34 Histogram of Subjective Crash Alert Timing Ratings During Surprise Moving Trials (Study 2)

Alert Modality Appropriateness Questionnaire

Results from this questionnaire (administered at the end of each interface block of Alerted Stationary Trials) are shown in Table 3-19. Across crash alert types, the visual alerts were rated on average from “fair” to “good”, with the HUD receiving consistently higher attribute ratings than the HHDD visual alert (particularly for the intensity and size attributes). Across crash alert types, the auditory alerts were rated on average “just right”, with the speech alert receiving slightly higher mean loudness and mean duration ratings than the HHDD alert. Note that the actual dBa sound level of the non-speech and speech alerts were the same. In addition, across the three crash alert types employing an auditory alert (HUD + Non-Speech, HHDD + Non-Speech, and HHDD + Speech), 81% of drivers (ranging between 77%-83% across these alert types) indicated the radio should be muted during the alert. For the brake pulse alert, the strength of jerk and duration attributes were rated on average closest to “just right”.

Overall, these findings suggest that the crash alert modalities tested were overall rated good/just right, with the exception of the HHDD which received “fair” ratings on size and intensity. Each of the crash alert types tested were chosen to represent realistic production constraints (e.g., the direct view HHDD could not be placed higher and more central in the driver’s field of view without the telltale module interfering with a 5th %tile female driver’s view of the road.) In light of current production constraints, and the overall good/just right ratings that were attained, the identical alert modality components were used in Study 3 and Study 4, with one exception. The loudness of the auditory alerts was increased from 67.4 dBa to 73.7 dBa in the following studies.

Table 3-19 Mean Ratings from Alert Modality Appropriateness Questionnaire Findings (Study 2)

	Crash Alert Type			
Modality/Attribute	**HUD + Non-Speech**	**HHDD + Non-Speech**	**HHDD + Speech**	**HHDD + Brake Pulse**
Visual				
Intensity	4.0	3.0	3.0	2.7
Size	3.9	3.0	3.2	3.0
Color	4.0	3.6	3.5	3.4
Location	3.8	3.6	3.5	3.3
Auditory				
Loudness	3.8	3.8	4.0	N/A.
Duration	3.9	3.9	4.1	N/A.
Brake Pulse				
Strength of Jerk	N/A.	N/A.	N/A.	3.8
Duration	N/A.	N/A.	N/A.	3.6

Note: See Appendix A4 for excerpts from a copy of this questionnaire. On the attribute rating scale, for visual alerts, 2=Poor, 3=Fair, 4=Good, and 5=Excellent. For the loudness attribute, 3=Slightly Soft, 4=Just Right, and 5=Slightly Loud. For the auditory duration attribute, 3=Slightly Short, 4=Just Right, and 5=Slightly Long. For the strength of jerk attribute, 3=Slightly Weak and 4=Just Right. For the brake pulse duration attribute, 3=Slightly Short and 4=Just Right. N/A=Not applicable.

Crash Alert Appropriateness Questionnaire

An Analysis of Variance (ANOVA) was performed on each of the 14 statements employed in this questionnaire. The within-subjects variable analyzed was crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse), and the between-subjects variables analyzed were age (younger, middle-aged, or older) and gender (male or female). Due to the relatively large number of statistical tests carried out (which increases the probability of spuriously significant results (Hays, 1981), the criterion set for statistical significance was $p<0.01$. All statistically significant results met at least (and often exceeded) the adopted $p<0.01$ criterion.

Across all 64 cells formed by combining the 4 crash alert types by 14 sound statements, the mean statement ratings (averaging over both age and gender) ranged from 3.7 to 6.1 (where 3=perhaps disagree, 4=neutral, 5=perhaps agree, 6=moderately agree, and 7=strongly agree). Overall, there were little or no statistically significant differences found between the four crash alert types examined. The differences found, which were relatively small in magnitude, were for the following subset of the 14 statements rated:

Crash Alert Appropriateness Statements

5. This method would NOT startle me, that is, cause me to blink, jump, or make a rapid reflex-like movement.

6. This method would NOT interfere with my ability to make a quick and accurate decision about the safest driving action to take (brake, steer, brake and steer, do nothing).

8. This method would NOT annoy me if the alert came on once a week in a situation where no driving action was required.

10. This method would NOT appear out of place in a car or truck.

11. This method would clearly tell me that I am in danger and need to react immediately.

13. This method of presenting crash alert information would get my attention without being overly annoying.

For Question #8 (not annoying), there was a main effect of Crash Alert Type. The mean ratings for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse conditions were 5.0, 4.7, 4.0, and 4.0, respectively. Follow-up planned comparison tests indicated significantly lower annoyance ratings in the HUD + Non-Speech condition relative to the HHDD + Speech and HHDD + Brake Pulse conditions. It should be noted that a similar trend was observed for question #9 (not annoying) at the $p<0.05$ level, which assumed alerts requiring no action occurred once a day (as opposed to the “once a week” assumption in Question #8).

There was also a main effect of Crash Alert Type for Question #6 (not interfering). The mean ratings for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD +

Brake Pulse conditions were 5.8, 5.5, 5.2, and 4.9, respectively. Follow-up planned comparison tests did not reveal any significant differences, although it is interesting that the general trend across the crash alert types examined for this question parallels that found for Question #8 (not annoying).

There was also an Age x Crash Alert Type interaction for Question #6 (not interfering), as well as for Question #5 (not startling). For Question #6, the mean ratings for younger drivers for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse conditions were 5.4, 5.3, 4.4, and 4.9, respectively. The corresponding mean ratings for the middle-age drivers were 5.9, 5.6, 5.3, and 3.9, respectively, and the corresponding mean ratings for the older drivers were 6.1, 5.8, 5.9, and 6.0, respectively. These results suggest these interference effects were restricted to younger and middle-aged drivers, and that overall, interference effects were particularly associated with the HHDD + Brake Pulse crash alert type for middle-age drivers. For Question #5 (not startling), the mean ratings for younger drivers for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse conditions were 4.6, 4.6, 3.6, and 4.5, respectively. The corresponding mean ratings for the middle-age drivers were 5.8, 5.3, 5.3, and 3.4, respectively, and the corresponding mean ratings for the older drivers were 5.5, 5.1, 5.3, and 6.0, respectively. These results indicate a fair amount of disagreement on startle ratings across age groups. The two lowest mean ratings (which indicates more startle) were given for the HHDD + Speech (3.6 rating) and HHDD + Brake Pulse (3.4 rating) conditions by the younger and middle-aged drivers, respectively. In contrast, the highest mean rating (which indicated less startle) was given for the HHDD + Brake Pulse (6.0 rating) condition by the older drivers.

There were also Gender x Crash Alert Type interactions for Question #10 (harmony), Question #11 (danger), and Question #13 (good method). Across these three question (#10, #11, and #13), the lowest (least desirable) mean ratings were provided by female drivers for the HHDD + Brake Pulse condition, whereas male drivers tended to rate the HHDD + Brake Pulse condition quite favorably. For Question #10 (harmony), the mean ratings for male drivers for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse crash alert types were 5.7, 6.0, 6.0, and 6.3, respectively. The corresponding mean ratings for the female drivers were 5.6, 5.9, 6.1, and 4.8, respectively. For Question #11 (danger), the mean ratings for male drivers for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse crash alert types were 5.9, 5.3, 5.5, and 6.0, respectively. The corresponding mean ratings for the female drivers were 6.3, 6.0, 6.2, and 4.8, respectively. For Question #11 (good method), the mean ratings for male drivers for the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, and HHDD + Brake Pulse crash alert types were 5.9, 5.3, 4.9, and 6.3, respectively. The corresponding mean ratings for the female drivers were 6.0, 5.7, 5.8, and 4.8, respectively.

Overall, these results generally indicated less desirable statement ratings associated with the HHDD + Brake Pulse condition (e.g., annoyance), and in some instances, with the HHDD + Speech condition. In some cases for the HHDD + Brake Pulse condition (i.e., the harmony, danger, and good method statements), this trend was primarily restricted to female drivers (whereas male drivers provided favorable ratings for the HHDD + Brake Pulse condition). It should be also noted that with the exception of Question #10 (harmony), the HUD + Non-Speech condition received the highest (most desirable) mean rating for each of the statements examined.

Build an Interface Questionnaire

Results from this questionnaire (administered at the end of testing, after the Follow-On Moving Trials) are shown in Table 3-20. A few drivers were eliminated from analysis either because they failed to complete the questionnaire or because they requested that a speech and non-speech alert be presented simultaneously.

Overall, for the 1-stage alert, 3, 12, and 6 drivers requested single-, dual-, and tri-modality crash alerts, respectively. The strong driver preference against a single-modality crash alert approach (18 of 21 drivers) provides support for a multi-modality crash alert approach (particularly a dual-modality crash alert approach) in terms of accommodating driver preferences. Sixteen of 21 drivers wanted a visual alert component as part of the crash alert, 18 of 21 drivers wanted an auditory alert component as part of the crash alert, and 11 of 21 drivers wanted a brake pulse component as part of the crash alert. For those selecting a visual alert, 13 of 16 drivers chose a HUD over the HHDD. For those selecting an auditory alert, 9 drivers wanted a speech warning and 9 drivers wanted a non-speech warning. The most frequent requests (selected by 4 drivers each) were the HUD + Non-Speech and HUD + Non-Speech + Brake Pulse combinations. Hence, the preference for the HUD visual alert, and the HUD and non-speech combination as part of the crash alert, were the most interesting results. However, it should be noted that together, these two most frequent requests were only selected by 8 of the 21 drivers.

For the 2-stage alert, there was wide disagreement between drivers, which may in part be due to drivers having no direct prior experience with 2-stage crash alerts and/or having difficulties understanding the 2-stage crash alert concept. Overall, for the cautionary part of the crash alert, 15 and 5 drivers requested single- and dual-modality crash alerts, respectively. 10 of 20 drivers wanted a visual alert component as part of the cautionary crash alert, 12 of 20 drivers wanted an auditory alert component as part of the cautionary crash alert, and only 3 of 20 drivers wanted a brake pulse component as part of this cautionary crash alert. For those selecting a visual alert, 8 of the 10 drivers chose a HUD over the HHDD. For those selecting an auditory alert, 9 drivers wanted a speech warning and 3 drivers wanted a non-speech warning. The most frequent requests were the single-modality alerts (selected by 6 drivers each) involving the HUD and speech alerts. In sharp contrast to the strong multi-modality alert preferences described above for a 1-stage crash alert, for the cautionary portion of the 2-stage alert, there was a strong preference for a single-modality alert (15 of 20 drivers).

Overall, for the imminent part of the 2-stage crash alert, 10, 5, and 5 drivers requested single-, dual-, and tri-modality crash alerts, respectively. Seven of 20 drivers wanted a visual alert component as part of the imminent crash alert, 17 of 20 drivers wanted an auditory alert component as part of this imminent crash alert, and 11 of 20 drivers wanted a brake pulse component as part of this imminent crash alert. For those selecting a visual alert, 5 of the 7 drivers chose a HUD over the HHDD. For those selecting an auditory alert, 8 drivers wanted a speech warning and 9 drivers wanted a non-speech warning. As with the cautionary portion of this 2-stage alert, the most frequent requests were single-modality alerts (selected by 4 drivers each) involving the HUD and speech alerts. Once again, in contrast to the strong multi-modality alert preferences described above for a 1-stage crash alert, for the imminent portion of this 2-stage alert, there was no strong preference for a multi-modality warning (10 of 20 drivers).

In terms of alert modality, preference shifts when transitioning between the cautionary and imminent stages of a 2-stage alert. A decrease in requests for visual alerts (from 10 to 7), an increase in requests for auditory alerts (from 12 to 17), and a substantial increase in brake pulse alert requests (from 3 to 11). A more detailed look at the responses indicated that the most consistent pair (observed for only 5 of the 20 drivers) involved a HUD cautionary alert followed by a non-speech imminent alert. For 2 of these 5 drivers, a brake pulse crash alert component was also included as part of the imminent alert.

In summary, results from this questionnaire indicate a strong preference for a HUD over HHDD visual alert. No clear preferences for a speech versus non-speech alerts, and a substantially weaker preference for including a brake pulse component in the cautionary portion of a 2-stage alert relative to the imminent portion of a 2-stage alert. Interestingly, there was substantially no difference in the number of auditory alert and brake pulse alert requests in the imminent portion of a 2-stage alert relative to the 1-stage alert scenario. However, the number of visual alert requests were about twice as high in the 1-stage alert scenario relative to the scenario involving the imminent portion of a 2-stage alert. These results suggested that, overall, drivers perceived the 1-stage alert to be closer to the imminent (relative to the cautionary) portion of a 2-stage crash alert.

Table 3-20 Build an Interface Questionnaire Findings for 1-Stage and 2-Stage Crash Alert Scenarios (Study 2)

	Crash Alert Type Request					Number of Requests		
	Visual Component		Auditory Component					
Crash Alert Modality Type	**HUD**	**HHDD**	**Non-Speech**	**Speech**	**Brake Pulse**	**For 1-Stage Alert**	**For 2-Stage Caution-ary**	**For 2-Stage Imminent**
Single-Modality	✓					0	6	0
			✓			2	1	4
				✓		1	6	4
					✓	0	2	2
Dual-Modality	✓		✓			4	0	1
	✓			✓		2	2	0
	✓				✓	2	0	0
		✓	✓			1	1	0
		✓		✓		0	1	0
		✓			✓	1	0	1
				✓	✓	2	0	1
			✓		✓	0	1	2
Tri-Modality	✓			✓	✓	4	0	3
	✓		✓		✓	1	0	1
		✓	✓		✓	1	0	1

Note: See Appendix A6 for a copy of this questionnaire. Only requested crash alert types are listed.

Name the System Questionnaire

This questionnaire was administered at the end of testing, after the Follow-On Moving Trials. Results from the open-ended portion of this questionnaire were not particularly informative for assessing a driver-preferred system name. No name was mentioned more than twice. 10 of the 23 drivers included the word “Alert” as part of the proposed system name, whereas 6 of the 23 drivers included the word “Warning” as part of the proposed system name. However, the interpretation of these “Alert” versus “Warning” results is somewhat unclear, since during the driver’s testing session, the various crash alerts tested were referred to “alerts”. These references may have influenced drivers’ generation of a proposed system name.

Results for the ranking portion of this questionnaire are shown in Table 3-21. These proposed system name choices are listed in the order of number of total votes received in the top three choices (which is shown in the rightmost column of Table 3-21). There are several interesting trends that can be observed. First, the only name that was picked in the top three by more than half of the drivers was “Forward Collision Warning.” Second, three of the top four names included “Collision Warning” as part of the system name (as opposed to “Crash Warning” or “Accident Warning”). Third, the two top choices included “Forward” as part of the system name (as opposed to “Front-end” or “Rear-end”).

It should be stressed that this naming data is strictly based on driver preferences, and does not provide direct data on what driver expectations (in terms of system performance) would be associated with each of these proposed names. During the middle-portion of this CAMP FCW system program, the name of the system being addressed in this program was changed from “Forward Collision Warning” to “Rear-end Collision Warning” in an attempt to communicate to the driver that the system was designed only for responding to vehicles ahead, and not, for example, for detecting pedestrians.

In the following study (Study 3) a similar questionnaire was administered. Unlike in the current study, drivers were informed that this feature was not designed to detect pedestrians, and that this feature would occasionally alert or warn the driver under conditions which pose no threat to the driver. Furthermore, the eight choices examined in the following study were compiled by selecting the top four choices listed in Table 3-21, and adding four identical system name choices which using the word “alert” rather than “warning.”

Table 3-21 Name the System Questionnaire Findings (Study 2)

Proposed System Name	Number of Votes			
	Best Choice	Second Choice	Third Choice	In Top Three
Forward Collision Warning System	4	6	3	13
Forward Crash Warning System	7	1	1	9
Front-end Collision Warning System	4	3	2	9
Rear-end Collision Warning System	3	2	4	9
Forward Accident Warning System	0	1	6	7
Front-end Accident Warning System	3	1	2	6
Rear-end Accident Warning System	0	3	2	5
Front-end Crash Warning System	1	2	1	4
Rear-end Crash Warning System	0	3	1	4

Note: See Appendix A7 for a copy of this questionnaire. 24 drivers provided ratings.

3.8 Study 3 Experimental Methodology and Approach

Unexpected Braking Event with "Unexplained" FCW Crash Alerts

Building upon the solid foundation provided by the results obtained from CAMP Study 1 and Study 2, this study further examined how and when to present crash alert information to a relatively inattentive driver. An overview of the experimental methodology and approach used in this study is shown in Table 3-11, and an overview of the order of experiment events (or procedures) in this study is shown in Table 3-12. Unlike Study 2, a completely new set of test drivers was tested who had not previously participated in CAMP Study 1. In sharp contrast to Study 2, drivers in this study were not informed at the beginning of the study that the purpose of this research was to address the usefulness of FCW system crash alerts for helping drivers avoid rear-end collisions.

In this study, the Surprise Moving Trial occurred during the first phase of the study. In this early phase, the on-board computer was allegedly "learning" driver's normal following behavior for a later "automatic distance control" phase. Drivers were simply asked to follow the lead vehicle at their "normal" following distance. The backseat experimenter was engaging the driver in a structured Question and Answer (Q & A) background information dialogue when the Surprise Moving Trial was introduced. Prior to this event, these (naïve) drivers were completely unaware the vehicle was equipped with a FCW system crash alert.

After the Surprise Moving Trial, drivers were asked a series of questions about whether they noticed anything coming on or happening inside the car before they began braking. This trial was then followed by two Follow-On Moving Trials using the same alert type used for the Surprise Moving Trial, and then two Follow-On Moving Trials with a comparison alert type. As in Study 2, immediately after both the Surprise Moving Trial and the Follow-On Moving Trials, drivers were asked judge the appropriateness of the FCW system crash alert timing on a 7-point scale ranging from "much too early" to "much too late".

The timing of the crash alert information was again based on modeling results from CAMP Study 1, and utilized the most conservative crash alert timing approach used in Study 2 (i.e., the RDP timing). For both the Surprise Moving Trial and the Follow-On Moving Trials, driver RT was assumed to be 1.50 seconds.

Five different 1-stage FCW system crash alert types were evaluated, three of which were "carryovers" from Study 2. These carryovers included the HUD + Non-Speech, HHDD + Non-Speech, and HHDD + Speech crash alert type conditions. The two new crash alert types tested included a HHDD + Non-Speech condition in which the HHDD was flashed, which was added in an attempt to increase the noticeability of the HHDD alert. This alert is subsequently referred to as the *Flashing HHDD + Non-Speech* condition. The second new crash alert type tested involved adding the non-speech tone component to the HHDD + Brake Pulse crash alert type tested in Study 2, forming a 1-stage, tri-modality alert. This alert is subsequently referred to as the *HHDD + Brake Pulse + Non-Speech* condition. The non-speech tone component was added in an attempt to reduce the relatively slow brake RTs associated with the HHDD + Brake Pulse condition in Study 2, and to reduce any ambiguity associated with the brake pulse by simultaneously providing a non-speech alert.

3.8.1 Subjects

Test participants consisted of 15 males and 15 females in each of two different age groups; 40-57 and 60-66 years old. Corresponding mean ages for these two groups were 45 and 63 years old, respectively. Each driver was tested individually in one approximately 1 ½ hour session and paid $150 for their participation. It should be noted that drivers finished 1 hour earlier than they were led to believe, in order to be consistent with the test instruction rouse used in Part 1 of this study. Drivers were recruited by an outside market research recruiting firm, and were required to be "naive" drivers who had not previously participated in CAMP Study 1 or Study 2. Drivers who were ultimately allowed to participate were mailed the information letter shown in Appendix A8 prior to testing. A copy of the informed consent statement is provided in Appendix A9, which describes the various conditions that ruled out potential drivers from participating (which were nearly identical to the conditions used in CAMP Study 1).

3.8.2 Test Site

Data was gathered on the same straightaway used in CAMP Study 1 and Study 2. The road was closed to all other traffic during testing. All testing was conducted under daytime conditions under dry road and dry weather conditions.

3.8.3 Test Vehicles and the "Surrogate" (Lead Vehicle) Target

The SV, surrogate target, and POV were identical to that used in CAMP Study 1 and Study 2. Both the SV front seat, passenger-side experimenter and POV driver were trained General Motors Milford Proving Ground test drivers who had previous experience conducting brake tests. The SV and the POV test drivers communicated during the study via digital radio communication.

3.8.4 Data Acquisition System

The data acquisition system used was identical to that used in CAMP Study 2, with the exception of the following crash alert changes. The capability of flashing the HHDD was added. When flashed, the HHDD was flashed at a 4 Hz rate, with a 50% duty cycle (i.e., repeated cycles of 125 ms on and 125 ms off). In addition, the loudness of the alert sounds were increased such that the dBa levels (averaging over left and right channels) were approximately 74.8 and 72.6 dBa for the non-speech and speech sounds, respectively.

3.8.5 Procedure and Design

Procedures Before and After Test Trials

The procedures used were identical to those used in Study 2, with the exception of the test instructions (shown in Appendix A10). Prior to the start of the test session, subjects in the HUD + Non-Speech condition were instructed to adjust the HUD while viewing a "CAMP" logo, since HUD visibility is dependent on the driver's seated eye position. Subjects were told the HUD would be used in later testing. This HUD adjustment procedure was necessary to help ensure the HUD would be visible to the driver (i.e., the driver's eyes would be within the HUD eye box or viewing area) during the Surprise Moving Trial.

Test Phases / Driver Instructions

Unlike in Study 2, the Surprise Moving Trial in this study occurred during the first phase of the study. In this first phase, the computer was allegedly "learning" driver's normal following behavior for a later "automatic distance control" phase. Drivers were simply asked to follow the lead vehicle at their "normal" following distance. The backseat experimenter engaged the driver in a structured *Question & Answer* (*Q & A*) background information dialogue. The last two questions of the dialogue were as follows:

1. Can you tell me the make and model of the last three vehicles you owned prior to your current vehicle?

2. In your opinion, what is the best car you ever owned and why?

During this last question, the surprise braking event was introduced under the same conditions (30 mph POV speed, -0.37 g POV deceleration, and no brake lights) used in Study 2. This surprise trial technique will be referred to as the "*Background Q & A*" surprise technique. After this event, drivers were asked a series of questions shown below about whether they noticed anything coming on or happening inside the car before they began braking.

1. "Did you notice anything come on or happen inside the car before you began braking?"
   If yes, please describe what came on (please be as specific as possible).

2. Did you notice anything else come on or happen inside the car before you began braking?
   If yes, please describe what came on (please be as specific as possible).

If the driver did notice any of the crash alerts components coming on, they were asked a series of additional questions about the alert components that they did notice, which are shown below. If the driver did not report in an open-ended fashion any of the crash alerts components coming on, they were asked more specifically (one at a time) if they noticed a visual indicator, sound, or vehicle braking or jerk. Based on this experimenter prompting, if the driver then reported noticing any of the crash alerts components coming on, they were asked the questions below about the alert components that they did notice.

- If the driver noticed visual alert:

→ What color was the indicator?
→ Where was this indicator located?
→ Were there letters or a picture, or letters and a picture on the indicator?
If you saw letters, what word or words did they spell?
If you saw a picture, please draw or describe the picture?
What does this picture mean to you?

- If the driver noticed the auditory alert:

→ What was the type of sound you noticed?
→ Was the sound a tone or a word, or both?
If you heard a tone, please describe the sound.
If you heard a word, please say the word.

If drivers noticed the brake pulse alert, they were asked to describe the sensation.

In addition, after this Surprise Moving Trial, drivers were asked to judge the appropriateness of the crash alert timing using the same rating scale used during Study 2.

The Surprise Moving Trial was then followed by two comparable alerted trials using the same alert type, and then two comparable alerted trials with the comparison HHDD + Non-Speech alert type. In the condition in which the driver experienced the HHDD + Non-Speech alert during the Surprise Moving Trial, the comparison alert was a HHDD + Speech alert. During these Follow-On Moving Trials (the second phase of the study), drivers were instructed to brake immediately in response to the crash alert in order to avoid colliding with the artificial car.

In this study, five separate, 1-stage, multi-modality crash alert types were evaluated, which are indicated below:

- Head-Up Display (HUD) + Non-Speech Tone
- High Head-Down Display (HHDD) + Non-Speech Tone
- High Head-Down Display (HHDD) + Speech
- High Head-Down Display (HHDD) + Non-Speech Tone + Brake Pulse
- Flashing High Head-Down Display (HHDD) + Non-Speech Tone

For crash alert timing, the RDP crash alert timing was employed with a 1.5 second driver brake RT assumption. The “bail-out” auditory alert for the front seat, passenger-side experimenter was also triggered based on the RDP crash alert timing approach, with assumed inputs of a 0.52 second driver (test driver) brake RT, and an assumed constant deceleration in response to the crash alert of -0.55 g’s. The “bail-out” sound, which was distinct from the non-speech tone employed, signaled the experimenter to take over braking using the add-on brake. A black cardboard visual barrier was placed between the driver and front seat experimenter which prevented the driver from anticipating (or being distracted by) the foot (braking) behavior of the experimenter, and allowed the experimenter to discretely let their foot hover over the add-on brake during a test trial.

Independent Variables Examined

For the Surprise Moving Trial and Follow-On Moving Trials, the between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse + Non-Speech, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female).

It should be noted that originally, additional analysis were planned for the Follow-On Trials to compare the first pair of trials, using the crash alert type experienced during the Surprise Moving Trial, to the second pair of Follow-On Moving Trials experienced with the comparison crash alert type (which in 4 of the 5 cases was the HHDD + Non-Speech condition). However, a strong order effect was found with the only two crash alert type conditions during which such an effect could be assessed (HHDD + Non-Speech/HHDD + Speech order versus the HHDD + Speech/HHDD + Non-Speech order). Hence, any comparisons between the first and second pair of Follow-On Moving Trials were deemed inappropriate, and all analyses were performed on the first pair of Follow-On Moving Trials in order to avoid confounding potential order effects.

Objective (Or Performance) Measures Examined

Same as those used in the Surprise Moving Trial and the Follow-On Moving Trials conditions of Study 2.

Subjective Measures / Questionnaire Data.

As in Study 2, immediately after each trial, drivers were asked to judge the appropriateness of the FCW system crash alert timing using the 7-point scale ranging from “much too early” to “much too late. These ratings were analyzed for each phase of the study using the same independent variables and analysis approach that was used to analyze the driver performance measures.

In addition, after the Surprise Moving Trial, drivers were asked various questions about what they noticed coming on or happening inside the car before they began braking. This is referred to as the *“alert noticeability”* questionnaire. These questions were previously described above in the “Test phases / Driver instructions” section.

At the end of the study, drivers were asked to fill out three separate questionnaires. First, drivers were administered the alert modality appropriateness questionnaire previously used in Study 2 after each pair of Follow-On Moving Trials. Second, drivers were administered the crash alert appropriateness questionnaire used in Study 2. Third, drivers were administered the rank order portion of the name the system questionnaire used in Study 2. This revised questionnaire is shown in Appendix A11. Unlike Study 2, drivers were informed that the feature they were to name was not designed to detect pedestrians, and that this feature would occasionally alert or warn the driver under conditions which pose no threat to the driver. This change was made in order to be more consistent with current CAMP assumptions about FCW system performance. Drivers were asked to rank order the top three names from the following set of proposed system names, which are shown below. The eight system name choices below were compiled by selecting the top four choices found in Study 2 (see Table 3-21), and adding four identical system name choices which used the word “alert” rather than “warning.”

Proposed System Names

- Forward Collision Warning System
- Forward Collision Alert System
- Forward Crash Warning System
- Forward Crash Alert System
- Front-End Collision Warning System
- Front-End Collision Alert System
- Rear-End Collision Warning System
- Rear-End Collision Alert System

3.8.6 Results and Discussion

Overview of Statistical Analysis Approach for Objective Measures

For the analysis of the objective (or performance) measures, a factorial Analysis of Variance (ANOVA) was performed for each relevant performance measure (i.e., when the lead vehicle was moving) used in Study 1, along with the brake reaction time measure defined in Study 2. Data from the Surprise Moving Trial and Follow-On Moving Trials were analyzed separately during the statistical analysis. The criterion set for statistical significance was $p<0.05$. Unless otherwise noted, all statistically significant results indicated met (and often exceeded) these adopted criterion.

Objective (or Performance) Measures

Surprise Moving Trial

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse + Non-Speech, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). During 2 of these 60 Surprise Moving Trials, the passenger-side experimenter intervened to assist the driver in coming to a stop, but the driver contacted the brake first. This occurred once in the HUD + Non-Speech condition, and once in the Flashing HHDD + Non-Speech. It remains unclear whether these drivers could have avoided impact with the surrogate target without the assistance of the passenger-side experimenter. In these two cases, the data obtained at onset of braking was included in the analysis, but any measures obtained throughout or at the end of braking were excluded from the analysis.

The brake RT findings are shown in Figure 3-35. Unlike Study 2, these results did not indicate a main effect of crash alert type on brake RTs. However, a planned comparison test did find there was a significant effect of faster brake RTs in the HHDD + Non-Speech relative to the HHDD + Speech condition. One hypothesis for these findings is that the use of the non-speech component across 4 of the 5 crash alert types examined in effect neutralized any differences between the various crash alert types. Partial support for this hypothesis comes from a planned comparison of brake RTs in the HHDD + Speech condition relative to the remaining four crash alert types combined, all of which have a non-speech component. Although, results did not quite reach statistical significance ($p<0.11$), this comparison does provide some support for this “non-speech tone neutralization” hypothesis.

Figure 3-36 provides the brake RT distribution (based on 60 RTs) during these Surprise Moving Trials for all drivers. It is worth noting that no subject yielded a brake RT higher than the 1.5 second brake RT assumed for crash alert timing purposes. This distribution is overall quite similar to the upper-percentile distribution found in Study 2 (see Figure 3-32), with a 0.13 second lower 85th %tile value and a 0.16 second lower 95th %tile value.

There were also significant main effects of crash alert type on a number of dependent measures, which are shown in Table 3-22, along with brackets indicating significant differences between pairs of conditions found from follow-up tests. These results generally indicate that the driver was in a more conservative (less aggressive) kinematic scenario in the HHDD + Brake Pulse + Non-Speech scenario relative to the HUD + Non-Speech and HHDD + Speech conditions (i.e., lower speed, TTC, and required deceleration values), and for a few variables (minimum headway and range) relative to the Flashing HUD + Non-Speech condition. There were no differences found between the HHDD + Brake Pulse + Non-Speech and the (steady) HHDD + Non-Speech condition.

For the dependent measures shown in Table 3-22, there was only one higher order interaction involving the crash alert type variable, and this was an Age x Crash Alert Type interaction with the minimum range measure. For the middle-age group, mean minimum ranges in the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Brake Pulse + Non-Speech, HHDD + Speech, and Flashing HHDD + Non-Speech conditions were 16, 13, 27, 10, and 6 feet, respectively. The corresponding mean minimum ranges for the older age group were 11, 13, 19, 23, and 17 feet, respectively. (For a point of reference, as mentioned in the CAMP Study 1 report, 1 mid-size car length is about 16 feet.). These minimum range data are not straightforward to interpret, since a small minimum range can be obtained within the context of a hard stop or more of a coasting, rolling stop.

In summary, as in Study 2, results from the Surprise Moving Trial indicate that the fastest mean brake reactions times occurred in the HUD + Non-Speech and HHDD + Non-Speech conditions, and brake RTs were significantly faster in the HHDD + Non-Speech relative to the HHDD + Speech condition. It is also worth noting that, in comparing mean brake RTs from Study 2 to those in the current study, brake RTs were reduced by 30% by adding a non-speech component to the HHDD + Brake Pulse crash alert type examined in Study 2. It is also interesting to note that, overall, the distribution of all brake RTs observed during these trials is very similar (albeit with times slightly lower in the upper percentiles) to those observed in Study 2. Finally, results found for the TTC-based and required deceleration measures suggest that the vehicle slowing, resulting from the brake pulse cue, resulted in the driver being in a more conservative kinematic scenario at SV braking onset relative to the HUD + Non-Speech and HHDD + Speech conditions (but not relative to the HHDD + Non-Speech and Flashing HHDD + Non-Speech conditions).

For reference and comparison purposes, Table 3-28 provides a list of various percentile values for key variables, along with the corresponding values for Study 2 Surprise Moving Trials for comparison purposes (previously shown in Table 3-17).

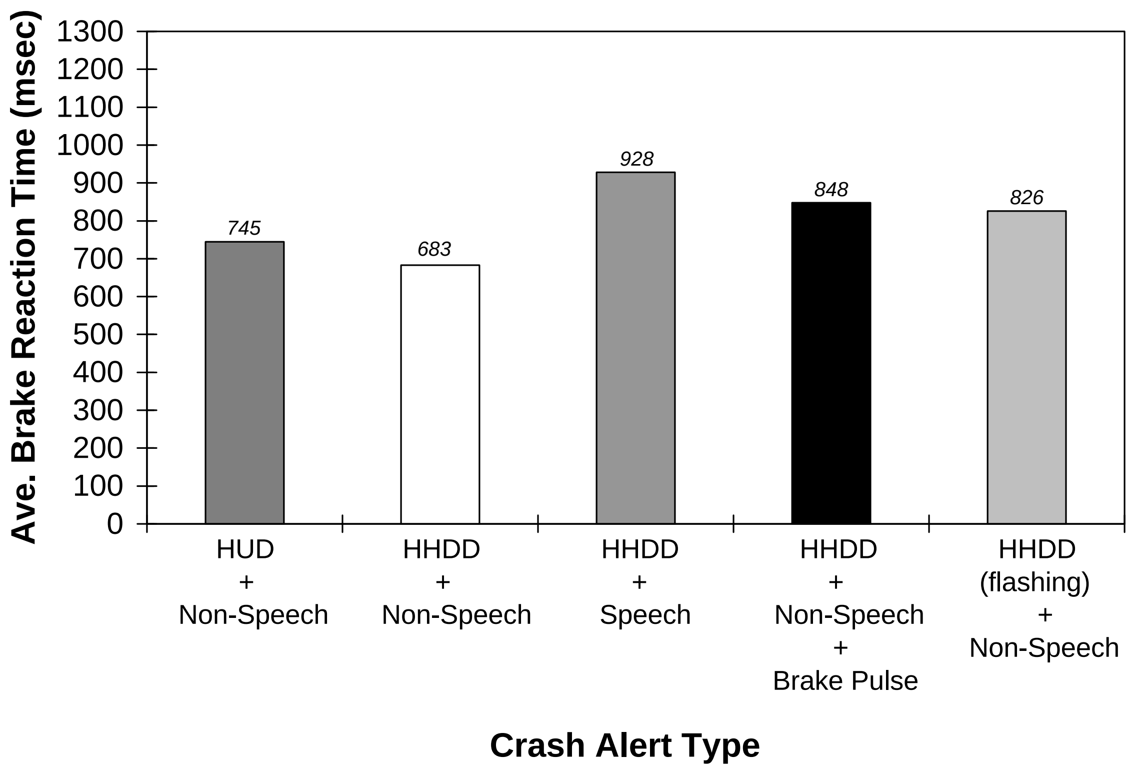


Figure 3-35 Ave. Brake Reaction Times During Surprise Trials as a Function of Crash Alert Type (Study 3)

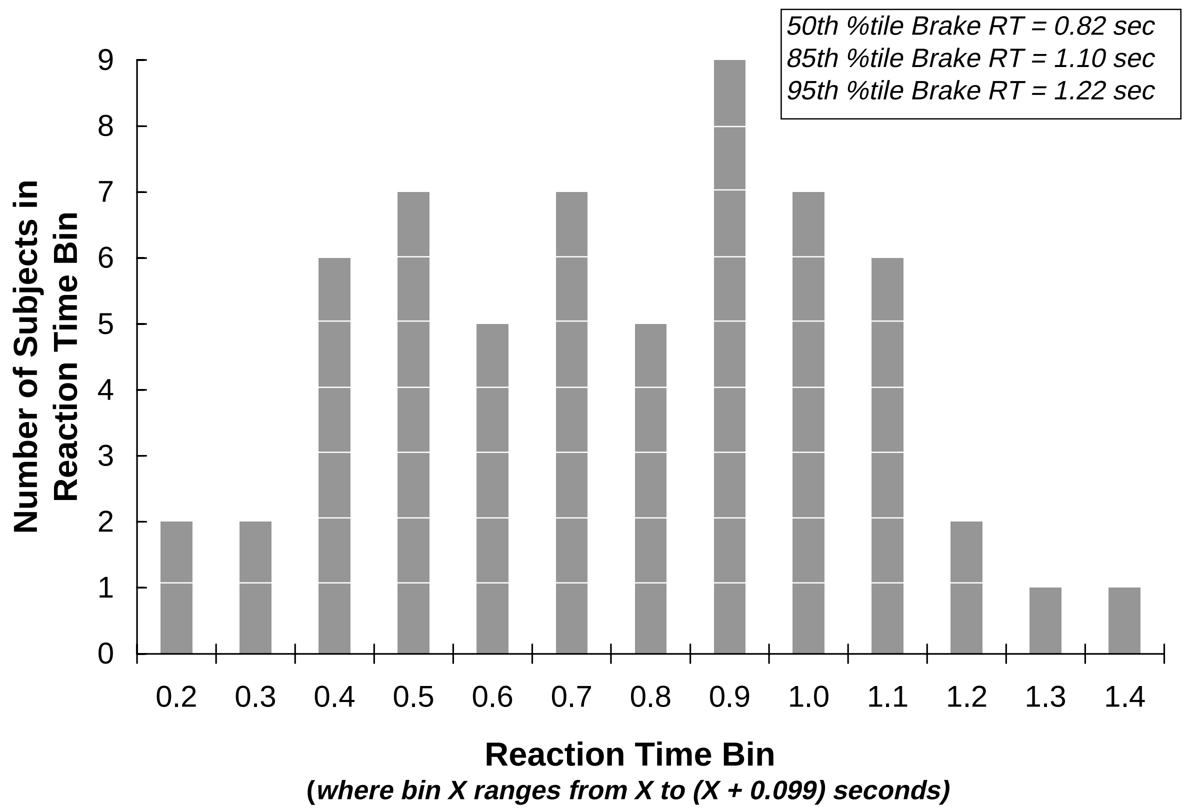


Figure 3-36 Brake Reaction Time Distribution During Surprise Moving Trials (Study 3)

Table 3-22 Significant Main Effects of Crash Alert Type on Various Driver Performance Measures During the Surprise Moving Trials, as well as Results from Follow-Up Tests (Study 3)

	At SV Braking Onset				Throughout Braking			
Crash Alert Type	**SV Speed (mph)**	**TTC / Case 1 (sec)**	**TTC / Case 2 (sec)**	**Req. Decel. (g)**	**Peak Decel. (g)**	**Min TTC / Case 2 (sec)**	**Min. Head-way (sec)**	**Min. Range (feet)**
HHDD + Non-Speech	31.1	7.1	2.7	-0.31	-0.52	2.6	1.3	13.5
HUD + Non-Speech	31.2	6.3	2.4	-0.34	-0.62	2.3	1.0	13.0
HHDD + Non-Speech + Br. Pulse	30.0	8.2	2.9	-0.28	-0.51	2.9	1.6	23.0
HHDD + Speech	31.3	5.3	2.4	-0.36	-0.60	2.2	1.1	16.2
HHDD Flashing + Non-Speech	30.8	6.2	2.5	-0.34	-0.53	2.5	1.1	11.2

Note: Brackets indicating significant differences between pairs of conditions found from follow-up tests.

Table 3-23 Percentile Values for Key Driver Performance Measures During Surprise Moving Trials for Study 3 (Across All Combinations of Age, Gender and Crash Alert Type Variables)

Time During Which Variable was Measured	**Dependent Measure (unit)**	**15th %tile Value**	**50th %tile Value**	**85th %tile Value**
At POV Braking Onset	Time Headway (sec)	1.1 *(1.0)*	1.6 *(1.5)*	2.1 *(1.9)*
At SV Braking Onset	Brake Reaction Time (sec)	0.46 *(0.59)*	0.82 *(0.84)*	1.10 *(1.23)*
	Required Deceleration (g)	-0.26 *(-0.28)*	-0.32 *(-0.33)*	-0.40 *(-0.42)*
Throughout Braking	Braking Distance (feet)	86 *(75)*	103 *(94)*	115 *(105)*
	Actual Deceleration (g)	-0.30 *(-0.35)*	-0.36 *(-0.42)*	-0.44 *(-0.47)*
	Peak Deceleration (g)	-0.44 *(-0.53)*	-0.55 *(-0.60)*	-0.64 *(-0.77)*
	Minimum Headway (sec)	0.5 *(0.6)*	1.3 *(1.2)*	1.7 *(1.6)*
	Minimum Range (feet)	4 *(5)*	15 *(17)*	23 *(28)*

Note: Numbers shown in parenthesis indicate corresponding values from Study 2 Surprise Moving Trials.

Follow-On Moving Trials

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse + Non-Speech, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). As in Study 2, results indicated no statistically significant effects on driver brake RTs during Follow-On Moving Trials. Across the crash alert type conditions examined, mean brake RTs ranged from 485 to 579 ms. Once again the lack of differences observed may be due to difficulties reported by the experimenter in getting the drivers focused on performing during these trials which were experienced immediately after the Surprise Moving Trial.

However, there were significant main effects of crash alert type on a number of dependent measures, where are shown in Table 3-24, along with brackets indicating significant differences between pairs of conditions found from follow-up tests. These results indicate that the driver was in a more conservative (less aggressive) kinematic scenario in the HHDD + Brake Pulse + Non-Speech scenario relative to the remaining crash alert type conditions (i.e., lower TTC, and required deceleration values). Unlike during the Surprise Moving Trial phase of this study, there were differences found between the HHDD + Brake Pulse + Non-Speech and the steady/flashing HHDD + Non-Speech conditions during this Follow-On Moving Trials phase.

For the dependent measures shown in Table 3-24, there was only one higher order interaction involving the crash alert type variable, and this was an Age x Gender x Crash Alert Type interaction with the minimum range measure. This interaction indicated that for each of the five crash alert types tested, the direction of the change in the mean minimum range from the middle-aged to older groups (i.e., either an increase or decrease in minimum range) was the exact opposite for the male relative to female groups. Of the 20 cells formed by this 3-way interaction, 3 of the 4 longest minimum ranges occurred in the HHDD + Brake Pulse + Non-Speech condition. However, as was mentioned earlier, these minimum range data are not straightforward to interpret, since a small minimum range can be obtained within the context of a controlled stop.

There were also Age x Gender x Crash Alert Type interaction effects on the following measures: range at POV braking onset, SV Speed at POV braking onset, headway at POV braking onset, range at SV braking onset, headway at SV braking onset, POV Speed at SV braking onset, and SV actual deceleration at SV braking onset. These 3-way interactions generally indicated that for the majority of the five crash alert types tested, the direction of the change in the measure of interest from the middle-aged to older groups (i.e., either an increase or decrease in the measure) was the exact opposite for the male relative to female groups. For both the range and headway measures at both POV braking onset and SV braking onset, the nature of this Age x Gender x Crash Alert Type interaction was very similar. For the male drivers, with the exception of the HHDD + Brake Pulse + Non-Speech crash alert type, the mean values were *lower* for the middle-aged relative to the older-aged group. In contrast, for the female drivers, with the exception of the HHDD + Brake Pulse + Non-Speech and HHDD + Non-Speech crash alert types, the mean values were *highe*r for the middle-aged relative to the older-aged group for 3 of the 5 crash alert types tested. For 4 out of the 5 crash alert types tested, (the exception being the HHDD + Non-

Speech condition), the direction of change in the measure of interest from the middle aged to older groups (i.e., either an increase or decrease in the measure) was the exact opposite for the male relative to female groups.

There were also a few statistically significant effects not involving the crash alert type variable. There was a main effect of age on mean peak deceleration values. For the middle-aged and older-aged groups, the mean peak deceleration values were -0.49 and -0.56, respectively. There was also an Age x Gender interaction for the TTC-Case 2 measure at SV braking onset. For the middle-aged group, the mean TTC-Case 2 values for male and female drivers were 2.8 and 3.1 seconds, respectively. The corresponding mean values for the older age group were 3.1 and 3.0 seconds, respectively.

In summary, as with the Surprise Moving Trial, results from the Follow-On Moving Trials indicate that the driver was in a more conservative (less aggressive) kinematic scenario in the HHDD + Brake Pulse + Non-Speech scenario relative to the remaining crash alert type conditions (i.e., lower TTC, and required deceleration values). Although there were differences found between the HHDD + Brake Pulse + Non-Speech and the steady/flashing HHDD + Non-Speech conditions (unlike results found for the Surprise Moving Trial phase of this study), these differences were not apparent for the required deceleration measure.

Table 3-24 Significant Main Effects of Crash Alert Type on Various Driver Performance Measures During Follow-On Moving Trials, as well as Results from Follow-Up Tests (Study 3)

	At SV Braking Onset			Throughout Braking		
Crash Alert Type	**Mean Current Dec. (g)**	**TTC / Case 2 (sec)**	**Req. Decel. (g)**	**Min TTC / Case 1 (sec**	**Min TTC / Case 2 (sec)**	**Min. Range (feet)**
HHDD + Non-Speech	-0.02	3.0	-0.27	3.1	3.0	25
HUD + Non-Speech	-0.02	2.8	-0.30	2.2	2.6	17
HHDD + Non-Speech + Br. Pulse	-0.10	3.4	-0.25	5.1	3.2	42
HHDD + Speech	-0.02	2.9	-0.29	3.7	2.8	29
HHDD Flashing + Non-Speech	-0.02	2.8	-0.30	2.9	2.7	22

Subjective Measures / Questionnaire Data

Crash Alert Timing Ratings

<u>Surprise Moving Trial</u>
The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). Recall, in this study phase, the RDP crash alert timing was used. Results indicated no statistically significant effects, with an overall rating of 4.1 (closest to "just right"). A histogram provided in Figure 3-37 shows the percent of responses at each point along the crash rating scale. Across all drivers, 58 total ratings were made. These data indicate that 69% of the timing responses were "just right", and 24% of the timing responses were either "slightly early" or slightly late."

<u>Follow-On Moving Trials</u>
The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). Once again, in this study phase, the RDP crash alert timing was used. Results indicated an overall rating of 3.9 (closest to "just right"), and an Age x Gender interaction. For male drivers, the mean crash alert timing ratings for the middle-aged and older groups were 3.6 and 4.3, respectively. For female drivers, the corresponding mean ratings were 3.8 and 3.7, respectively. Hence, the largest difference in ratings between gender groups occurred for the older age group.

The histogram provided in Figure 3-38 shows the percent of responses at each point along the crash rating scale. Across all drivers, 116 total ratings were made. These data indicate that 59% of the timing responses were "just right", and 32% of the timing responses were either "slightly early" or slightly late."

Summary of Crash Alert Timing Ratings Findings

In summary, these crash alert timing ratings are consistent with those found in Study 2, and provide further evidence that the crash alert timing approach directly derived/modeling from the CAMP Study 1 findings (i.e., the RDP crash alert timing) does an excellent job from a driver preference perspective under a wide range of driver expectancy conditions.

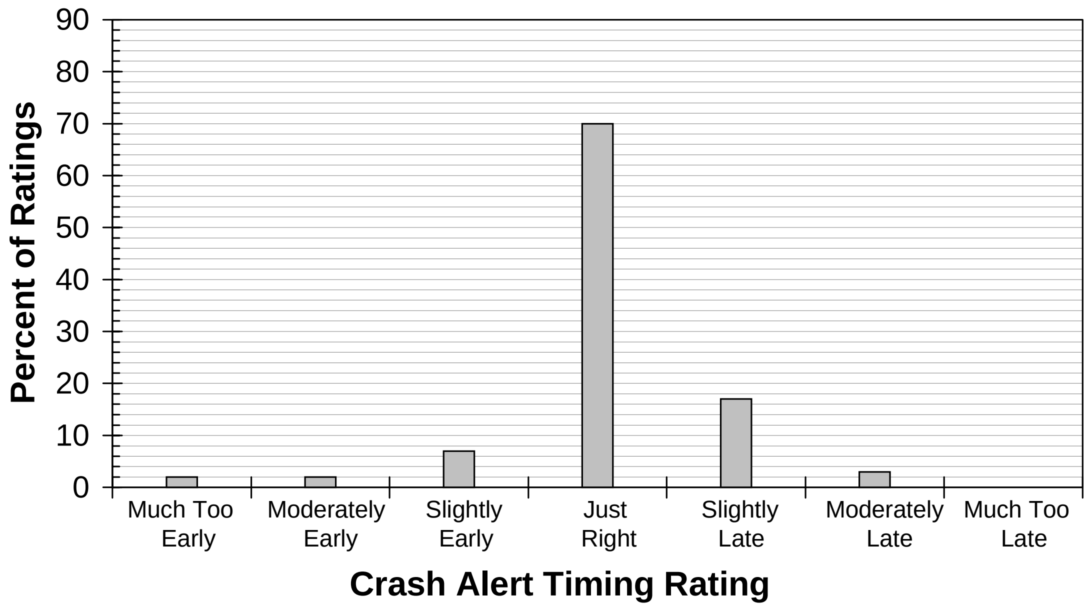


Figure 3-37 Histogram of Subjective Crash Alert Timing Ratings During Surprise Moving Trials (Study 3)

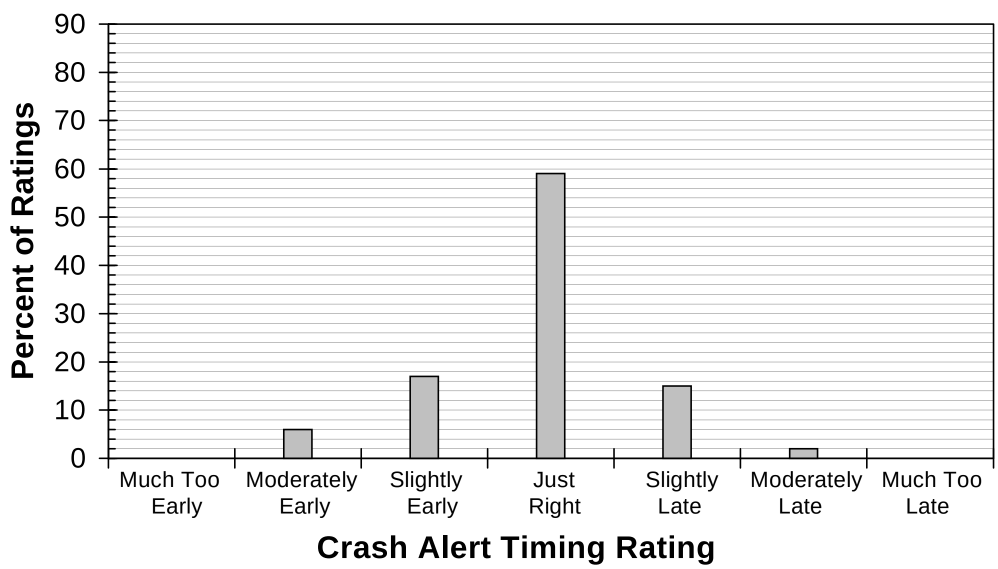


Figure 3-38 Histogram of Subjective Crash Alert Timing Ratings During Follow-On Moving Trials (Study 3)

Alert Noticeability Questionnaire

Results from this questionnaire (administered immediately after the Surprise Moving Trial) are shown in Table 3-25. The criterion for "noticeability" of these alerts during this first experience the driver had with each of these crash alert components were as follows. For the visual alert, noticeability was defined as correctly reporting either the presence of a flashing light, the HHDD location, the yellow/orange color, or the correct word or picture following either an open-ended report of the presence of a visual indicator or following an experimenter prompting if the driver noticed a visual indicator. For the auditory non-speech alert, the criterion for the noticeability was defined as correctly reporting the sound following either an open-ended report of the presence of the sound or following an experimenter prompting if they noticed a sound. For the speech alert, the criterion for the noticeability was defined as correctly reporting the word "Warning" following either an open-ended report of the presence of the speech alert or following an experimenter prompting if they noticed a sound. (It should be pointed out that nearly all drivers correctly described whether the sound was a tone versus speech message). For the brake pulse alert, the criterion for the noticeability was defined as correctly reporting a pulse-like sensation following either an open-ended report of or following an experimenter prompting if they noticed such a sensation (even if drivers were not sure of the source of the sensation during this initial experience with this alert). For the interested reader, a more detailed breakdown of these data beyond this high-level "noticeability" criterion is provided in Appendix A17. The decision to include experimenter-prompted responses to assess whether the noticeability criterion was met during subject's initial experience with the crash alert was due to the intentional vagueness of the open-ended questions (i.e., "Did you notice anything come on or happen inside the car?"), the ability to verify whether responses given by the driver were correct by examining their comments, and to perhaps facilitate driver recollections which may have been impacted by the surprise braking event and the driver's braking maneuver.

Across each of the three alert types combining a visual and auditory alert (HUD + Non-Speech, HHDD + Non-Speech, Flashing HHDD + Non-Speech), the non-speech component of the alert was noticed by all drivers. For the HHDD + Non-Speech + Brake Pulse and HHDD + Speech crash alert types, 11 of 12 drivers noticed the auditory component of the alert. In the one crash alert type including a brake pulse (HHDD + Non-Speech + Brake Pulse), the pulse was noticed by all drivers. This data provides direct evidence that the auditory alert and brake pulse profile established during pilot testing met the goal of providing crash alert components which would be clearly noticed by naive drivers. In summary, across all crash alerts, the auditory and brake pulse components of the alerts examined were noticed by a very high percentage of drivers, all of whom were completely unaware the vehicle was equipped with a FCW system crash alert during this first phase of testing. The descriptions provided by drivers of the brake pulse alert proved interesting. Two of the 12 drivers reported experiencing a bump. All of the remaining 10 of 12 drivers experiencing this alert reported a pulse-like sensation. Seven of these 10 drivers attributed the vehicle as the source of this sensation (using responses such as "vehicle hesitation", "braking", "jerk", and "like ABS" in their descriptions), whereas 3 of these 10 drivers could not readily identify the source of this pulse-like sensation (the vehicle, their own braking, or the road). These data suggest that when implementing a brake pulse alert, an additional alert modality component (visual and/or auditory) is merited to "explain" the source of the pulse-like sensation experienced by the driver (5 of the 12 drivers failed to quickly identify the vehicle as the source of this sensation) . However, it should be noted that under more typical conditions in which the driver would be aware his/her vehicle was equipped with a brake pulse crash alert, the driver may have little difficulty unambiguously identifying this pulse-like sensation as a crash alert.

In contrast, the noticeability of the visual alerts varied considerably across the crash alert types. In the (steady) HUD + Non-Speech and the Flashing HHDD + Non-Speech conditions, the visual alerts were noticed by 9 of 12 drivers and 8 of 12 drivers, respectively. In the three remaining crash alert type conditions (HHDD + Non-Speech, HHDD + Non-Speech + Brake Pulse, and HHDD + Speech), all of which employed a steady HHDD, the visual alerts were noticed by less than half of the drivers. In addition, it should be noted that, in general, drivers had great difficulty reporting any information with respect to the visual display format (i.e., the icon or word) based on this first experience with a visual crash alert, particularly in the HHDD (relative to the HUD) condition (see Appendix A17). As with the brake pulse alert, under more typical conditions in which the driver would be aware that his/her vehicle was equipped with a visual crash alert, the probability of noticing these visual alerts may increase.

These visual alert data suggest that flashing the HHDD may be prudent in order to improve the noticeability of the HHDD (which is also likely to be true for the HUD). This flashing issue was further examined in Study 4 under Surprise Moving Trial conditions in which the driver was asked to search for a (non-existent) indicator light located at the head-down, conventional instrument panel. These conditions tested this flashing hypothesis under conditions in which the anticipated visual angle between the driver's eyes and both the visual crash alert location and the lead vehicle braking event location were substantially increased relative to the current study.

Table 3-25 Noticeability of Visual, Auditory, and Brake Pulse Alerts Across Various Crash Alert Types (Study 3)

Crash Alert Type	Visual Alert Noticed?	Auditory Alert Noticed?	Brake Pulse Alert Noticed?
HUD + Non-Speech	9 / 12	12 / 12	N/A.
Flashing HHDD + Non-Speech	8 / 12	12 / 12	N/A.
HHDD + Non-Speech	5 / 12	12 / 12	N/A.
HHDD + Non-Speech + Brake Pulse	4 / 12	11 / 12	12 /12
HHDD + Speech	2 / 12	11 / 12	N/A.

Alert Modality Appropriateness Questionnaire

Results from this questionnaire (administered at the end of the Follow-On Moving Trials) are shown in Table 3-26. For comparison purposes, also provided are corresponding ratings from the previous Study 2. However, unlike Study 2, these ratings were between-subjects, and were made with much less experience with both the crash alerts experienced and alternative crash alert types. Hence, in general, these ratings are considered less valuable than those found in Study 2. The ratings provided in Table 3-26 are based on the Surprise Moving Trial and the next two Follow-On Moving Trials (all conducted with the same crash alert type).

Across crash alert types, the visual alerts were rated on average from “fair” to “good”. As in Study 2, the HUD generally received higher attribute ratings than the HHDD crash alert component (particularly for the intensity and size attributes). Across crash alert types, the auditory alerts were rated on average “just right”, with the speech alert, as in Study 2, receiving slightly higher mean loudness and mean duration ratings than the non-speech alert. Note that the actual dBa sound level of the speech alert was slightly lower. Also, it is worth noting that the loudness ratings were higher in this study relative to the previous Study 2, which could be explained by the approximately 6 dBa sound level increase in the auditory sounds employed in this study. In addition, overall, 70% of drivers (ranging between 50%-83% across all crash alert types tested) indicated the radio should be muted during the alert. For the brake pulse alert, the strength of jerk was rated on average between “slightly weak” and “just right” and the duration was rated between “slightly short” and “just right.”

Overall, these findings are very consistent with those found in Study 2. The crash alert modalities tested were overall rated good/just right, with the exception of the HHDD which again received low ratings on size and intensity. The loudness ratings for the auditory alerts increased over Study 2, most likely due to the increase in sound levels employed in this study. Finally, across both Study 2 and Study 3, overall, about 3 of 4 drivers indicated that the radio should be muted during the crash alert sound presentation.

Table 3-26 Mean Ratings from Alert Modality Appropriateness Questionnaire Findings (Study 3)

	Crash Alert Type				
Modality/Attribute	**HUD + Non-Speech**	**HHDD + Non-Speech**	**HHDD + Speech**	**HHDD + Non-Speech + Brake Pulse**	**Flashing HHDD + Non-Speech**
Visual					
Intensity	3.8 (*4.0*)	3.0 (*3.0*)	2.8 (*3.0*)	3.0 (*2.7*)	3.9
Size	3.8 (*3.9*)	3.7 (*3.0*)	3.0 (*3.2*)	3.3 (*3.0*)	3.4
Color	4.0 (*4.0*)	3.4 (*3.6*)	2.8 (*3.5*)	3.2 (*3.4*)	3.9
Location	4.0 (*3.8*)	4.2 (*3.6*)	3.3 (*3.5*)	3.7 (*3.3*)	3.5
Auditory					
Loudness	4.3 *(3.8)*	4.1 *(3.8)*	4.5 (*4.0*)	4.4 (*N/A.*)	4.5
Duration	4.3 *(3.9)*	4.2 *(3.9)*	3.9 (*4.1*)	3.8 (*N/A.*)	3.9
Brake Pulse					
Strength of Jerk	N/A.	N/A.	N/A.	3.5 (*3.8*)	
Duration	N/A.	N/A.	N/A.	3.5 (*3.6*)	

Note: See Appendix A4 for excerpts of a questionnaire identical to the one used in this Study. Above ratings are based on the Surprise Moving Trial and first two Follow-On Moving Trials (all experienced with the same crash alert type). Hence, relative to Study 2, these ratings are based on much more limited experience with the crash alert type being rated, as well as other crash alert types. With the exception of the HHDD + Non-Speech + Brake Pulse crash alert type, all italicized numbers shown in parentheses are corresponding ratings found for the same crash alert type in Study 2. For the HHDD + Non-Speech + Brake Pulse condition, the italicized numbers are corresponding ratings found for the HHDD + Brake Pulse conditions in Study 2 provided for comparison purposes. On the attribute rating scale, for visual alerts, 2=Poor, 3=Fair, 4=Good, and 5=Excellent. For the loudness attribute, 3=Slightly Soft, 4=Just Right, and 5=Slightly Loud. For the auditory duration attribute, 3=Slightly Short, 4=Just Right, and 5=Slightly Long. For the strength of jerk attribute, 3=Slightly Weak and 4=Just Right. For the brake pulse duration attribute, 3=Slightly Short and 4=Just Right. N/A=Not applicable.

Crash Alert Appropriateness Questionnaire

An Analysis of Variance (ANOVA) was performed on each of the 14 statements employed in this questionnaire. The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse + Non-Speech, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). Due to the relatively large number of statistical tests carried out (which increases the probability of spuriously significant results, (Hays, 1981)), the criterion set for statistical significance was $p<0.01$. Unlike Study 2, these ratings were made between-subjects, and were made with much less experience with both the crash alerts experienced and alternative crash alert types. Hence, in general, these ratings are considered less valuable than those found in Study 2. The ratings analyzed were based on the Surprise Moving Trial and the next two Follow-On Moving Trials (all conducted with the same crash alert type).

Across all 64 cells formed by combining the 5 crash alert types by 14 sound statements, the mean statement ratings (averaging over both age and gender) ranged from 3.0 to 6.8 (where 3=perhaps disagree, 4=neutral, 5=perhaps agree, 6=moderately agree, and 7=strongly agree). There were no statistically significant differences found between the five crash alert types examined. It should be also noted that with the exception of Question #11 (danger), either the HUD + Non-Speech or HHDD + Brake Pulse + Non-Speech conditions received the highest (most desirable) mean rating for each of the statements examined. This pattern of results for the HUD + Non-Speech condition is largely consistent with those found in Study 2, and the pattern of these ratings provides evidence that adding the non-speech component to the HHDD + Brake Pulse crash alert type tested in Study 2 substantially improved driver's subjective ratings of this crash alert type including a brake pulse component.

Name the System Questionnaire

This questionnaire was administered at the end of testing, after the Follow-On Moving Trials. Results for this questionnaire are shown in Table 3-27. The proposed system name choices are listed in the order of the total number of votes received in the top three choices (shown in the rightmost column of Table 3-27. There are several interesting trends that can be observed. First, there was no clear preference between including "Warning" versus "Alert" as part of the system name. Second, there appears to be a slight preference for including "Collision Alert" as part of the system name relative to "Collision Warning." However, the interpretation of both these results is somewhat unclear, since during the driver's testing session, the various crash alerts tested were referred to simply as "alerts", and these references may have influenced drivers' naming judgments. Third, as in Study 2, the top name included "Forward Collision" as part of the system name, in spite of instruction that the system was not designed for detecting pedestrians.

It should be stressed once again that this naming data is strictly based on driver preferences, and does not provide direct data on what driver expectations (in terms of system performance) would be associated with each of these proposed names. An "open-ended" questionnaire employing naive drivers would provide more direct data for assessing the association between system name and driver expectations.

Table 3-27 Name the System Questionnaire Findings (Study 3)

Proposed System Name	Number of Votes			
	Best Choice	**Second Choice**	**Third Choice**	**In Top Three**
Forward Collision Alert System	12	10	7	29
Front-end Collision Alert System	7	11	9	27
Rear-end Collision Warning System*	6	10	10	26
Front-end Collision Warning System*	10	7	8	25
Forward Collision Warning System*	9	4	9	22
Rear-end Collision Alert System	8	4	7	19
Forward Crash Alert System	5	10	1	16
Forward Crash Warning System*	3	4	9	16

Note: See Appendix A11 for a copy of the questionnaire. "*" denotes proposed system name carried over from Study 2. 60 subjects provided ratings. It should be noted that unlike Study 2, subjects in this study were informed that feature is not designed to detect pedestrians, and that this feature would occasionally alert or warn the driver under conditions which pose no threat to the driver.

3.9 Study 4 Experimental Methodology and Approach

Unexpected Braking Event with "Unexplained" FCW Crash Alerts / Braking in Response to Expected FCW Crash Alerts Under Lead Vehicle Moving Conditions

Building upon the solid foundation provided by the results obtained from CAMP Study 1, Study 2, and Study 3, this study further examined how and when to present crash alert information to both an attentive and relatively inattentive driver. An overview of the experimental methodology and approach used in this study is shown in Table 3-11, and an overview of the order of experiment events (or procedures) in this study is shown in Table 3-12. As in Study 2, a subset of the test participants used in CAMP Study 1 was tested (who were not participants in either Study 2 or Study 3). As in Study 3, drivers in this study were not informed at the beginning of the study that the purpose of this research was to address the usefulness of FCW system crash alerts for helping drivers avoid rear-end collisions.

As in Study 3, the Surprise Moving Trial occurred during the first phase of the study. Once again, the on-board computer was allegedly "learning" driver's normal following behavior for a later "automatic distance control" phase, and the backseat experimenter engaged the driver in a structured Q & A background information dialogue. The backseat experimenter engaged the driver in the exact same dialogue used in Study 3, except this dialog was interrupted by a request for the driver to search for a (non-existent) indicator light on the dashboard. As the driver was visually searching for the indicator, the Surprise Moving Trial was introduced. As in Study 3, drivers were completely unaware the vehicle was equipped with a FCW system crash alert. After the Surprise Moving Trial, drivers were then asked the series of questions used in Study 3 about what they noticed come on inside the car before they began braking, and were also asked to provide a crash alert timing rating.

This Surprise Moving Trial was then followed by a number of trials in which drivers were asked to brake in response to a FCW system crash alert as an attentive driver while approaching the moving surrogate target. The driver was instructed to follow the POV at their "normal" following distance while the POV traveled at 30, 45, or 60 mph. After this headway had been attained, the POV braked automatically at a constant deceleration rate of approximately 0.15, 0.27, or 0.36 g's, in the same manner as was used in CAMP Study 1. These types of trials are subsequently referred to as *Alerted Moving Trials*. The nine combinations formed by crossing the three POV speed levels by the three POV deceleration levels were nearly identical to those examined in CAMP Study 1. Hence, driver's braking behavior with a crash alert could be compared to previous data obtained under identical conditions without a crash alert (for the same driver), which is discussed toward the end of this Chapter immediately prior to the General Discussion section. As in Study 2 and Study 3, immediately after a trial, drivers were asked to judge the appropriateness of the FCW system crash alert timing on a 7-point scale ranging from "much too early" to "much too late". Finally, it should be noted that rather than run Follow-On Moving Trials as in the previous two studies (Study 2 and Study 3), driver performance during the Surprise Moving Trial was compared to performance during the equivalent Speed/POV braking profile conditions evaluated in the Alerted Moving Trials phase. It was felt this latter condition would provide a more stable, valuable comparison to performance observed in the Surprise Moving Trial than would be found with Follow-On Moving Trials, although it should be noted that driver brake RT assumptions are different across Surprise Moving Trials and Alerted Moving Trials. Often drivers would need some time to get refocused on the task instructions after the Surprise Moving Trial, which may have affected the subsequent Follow-On Moving Trials data gathered immediately following the Surprise Moving Trial.

The timing of the crash alert information was again based on modeling results from CAMP Study 1, and utilized the most conservative crash alert timing approach used in Study 2 (i.e., the RDP crash alert timing), and the identical crash alert timing approach used in Study 3. The decision not to test a more aggressive crash alert timing approach, as was done in Study 2, was made after looking at early data from this study which suggested that the alert timing approach employed was perceived as between “just right” and “slightly late”. For the Alerted Moving Trials, as in the Alerted Stationary Trials of Study 2, driver RT was assumed to be 0.52 seconds for crash alert timing purposes. For the Surprise Moving Trial, driver RT was assumed to be 1.50 seconds (as in Study 2 and Study 3).

The two different 1-stage, dual-modality, FCW system crash alert types evaluated were the steady HHDD + Non-Speech and flashing HHDD + Non-Speech crash alert types, both “carryovers” from Study 3. The rationale for selecting these two FCW system crash alert types for this study was based on the following considerations. First, in terms of an experimental strategy (as well as experimental efficiency), focusing the study on two crash alert types allowed exploring the same wide range of POV speed/POV braking profile combinations explored in Study 1. This provided an important opportunity to evaluate and validate the crash alert timing approach under a much wider range of conditions when the lead vehicle was moving. Second, in both Study 2 and Study 3, the HHDD + Non-Speech crash alert type provided good all-around performance in terms of both objective data (e.g., fast brake RTs) and subjective data (e.g., low driver annoyance ratings). Third, the HHDD + Non-Speech crash alert type (whether the HHDD is steady or flashing) has favorable qualities as a crash alert type approach from an industry-wide, international implementation perspective relative to speech alerts (which, in any case, performed poorly in terms of both objective and subjective data), HUD alerts (HUDs are not currently implemented industry-wide), and the relatively immature brake pulse alert. Hence, in terms of developing minimum requirements, it made the most sense to concentrate on gathering additional data with the HHDD and non-speech dual-modality approach with a different surprise trial technique (i.e., the head-down visual search task), which might provide a different Surprise Moving Trial brake RT distribution. Fourth, the issue of whether or not to flash the HHDD alert could be explored further under a surprise trial technique where the anticipated visual angle between the driver’s eyes and both the visual crash alert location and the lead vehicle braking event location were substantially increased.

3.9.1 Subjects

Test participants consisted of 4 males and 4 females in each of three different age groups; 20-31, 40-51, and 60-71 years old. Corresponding mean ages for these younger, middle-aged, and older age groups were 25, 46, and 65 years old, respectively. Each driver was tested individually in one approximately 2 to 2 ½ hour session and paid $150 for their participation. Drivers were recruited by an outside market research recruiting firm, and were required to be CAMP Study 1 participants who had not participated in the previous Study 2. Drivers who were ultimately allowed to participate were mailed the information letter shown in Appendix A12 prior to testing. A copy of the informed consent statement is provided in Appendix A13, which describes the various conditions that ruled out potential drivers from participating (which were nearly identical to the conditions used in CAMP Study 1).

3.9.2 Test Site

Data was gathered on the same straightaway used in CAMP Study 1, Study 2, and Study 3. The road was closed to all other traffic during testing. All testing was conducted under daytime conditions under dry road and dry weather conditions.

3.9.3 Test Vehicles and the “Surrogate” (Lead Vehicle) Target

The SV, surrogate target, and POV were identical to that used in CAMP Study 1, Study 2, and Study 3. Both the SV front seat, passenger-side experimenter and POV driver were trained General Motors Milford Proving Ground test drivers who had previous experience conducting brake tests. The SV and the POV test drivers communicated during the study via digital radio communication.

3.9.4 Data Acquisition System

The data acquisition system used was identical to that used in CAMP Study 3.

3.9.5 Procedure and Design

Procedures Before and After Trials

The procedures used were identical to those used in Study 2, with the exception of the test instructions. The test instructions given before and after the Surprise Moving trial are shown in Appendix A14 and Appendix A15, respectively.

Test Phases / Driver Instructions

As in Study 3, the Surprise Moving Trial in this study occurred during the first phase of the study. In this first phase, the computer again was allegedly “learning” driver’s normal following behavior for a later “automatic distance control” phase. The backseat experimenter engaged the driver in the same structured *Question & Answer* (*Q & A*) background information dialogue used in Study 3. This dialogue was interrupted by the following, which requested the driver to search for a (non-existent) indicator light located at the head-down, conventional instrument panel:

> *“Have you noticed the indicator light by the dashboard? It is located below the tachometer on the dash. It is a little blue-green indicator that is a little car with bars in front of it. I know it has been coming on. Can you find it? Once you find it I need you to tell me how may bars are in front of the car.”*

While the driver was visually searching for the indicator, the Surprise Moving Trial was introduced under the same POV conditions (30 mph speed, -0.37 g deceleration, no brake lights) used in Study 2 and Study 3. This surprise trial technique will be referred to as the “*Head-Down Telltale Search”* surprise technique. As in Study 3, drivers were completely unaware the vehicle was equipped with a FCW system crash alert. After the Surprise Moving Trials, drivers were asked a series of questions about what they noticed coming on or happening inside the car before they began braking. These questions were identical to those used in Study 3.

During the second phase of this study, drivers experienced trials in which the surrogate target was moving. The driver was instructed to follow the POV at their “normal” following distance while the POV traveled at 30, 45, or 60 mph. After this headway had been attained, the POV braked automatically at a constant deceleration rate of approximately 0.15, 0.27, or 0.36 g’s, in the same manner as was used in CAMP Study 1. These types of trials are subsequently referred to as *Alerted Moving Trials*. Drivers were asked to brake in response to the FCW system crash alerts as an attentive driver while approaching a surrogate target moving at 30, 45, or 60 mph. These types of trials are subsequently referred to as *Alerted Moving Trials*.

During this study, two 1-stage, dual-modality crash alerts were examined. These crash alert types are indicated below:

- Steady High Head-Down Display (HHDD) + Non-Speech Tone
- Flashing High Head-Down Display (HHDD) + Non-Speech Tone

Drivers were instructed to brake immediately in response to the crash alert in order to avoid colliding with the artificial car. When the SV came to a complete stop, data collection was halted and the trial was ended. During these Alerted Moving trials, drivers experienced two test blocks of 9 trials each (overall, 18 trials) with the same crash alert experienced during the Surprise Moving Trial. The 9 trials per block were formed by crossing the three POV speeds (30, 45, and 60 mph) with the three POV constant deceleration profiles (-0.15,-0.27, and -0.36 g’s). During these 9 trials, drivers experienced three successive trials in each speed condition (each with a different POV braking profile). The second block of trials provided a second repetition of the same conditions in order to examine learning effects. The order of the three approach speeds within a block and the three POV braking profile levels from trial-to-trial were appropriately randomized and counterbalanced.

For crash alert timing, the RDP crash alert timing was employed with a 1.5 second driver brake RT assumption for the Surprise Moving Trial (as in Study 2 and Study 3), and a 0.52 second driver RT assumption employed for the Alerted Moving Trials (as was used during the Alerted Stationary Trials in Study 2) for crash alert timing purposes. The “bail-out” auditory alert for the front seat, passenger-side experimenter was also triggered based on the RDP crash alert timing approach, with assumed inputs of 520 ms driver (test driver) brake RT, and an assumed constant deceleration in response to the crash alert of -0.55 g’s during the 30 mph condition, and -0.60 g’s during the 45 mph and 60 mph conditions. The identical “bail-out” sound used in Study 3 was employed here, as well as the visual barrier placed between the experimenter and front seat experimenter (which prevented the driver from anticipating test driver braking behavior).

Independent Variables Examined

For the Surprise Moving Trial, the between-subjects variables analyzed were crash alert type (Steady HHDD + Non-Speech or Flashing HHDD + Non-Speech), age (younger, middle-aged, or older), and gender (male or female). For the Alerted Moving Trials, the within-subjects variables analyzed were speed (30, 45, and 60 mph), POV braking profile (-0.15, -0.27, or -0.36 g), and repetition (first and second), and the between-subjects variables analyzed were crash alert type (Steady HHDD + Non-Speech or Flashing HHDD + Non-Speech), age (younger, middle-aged, or older), and gender (male or female).

Objective (or Performance) Measures Examined

The same driver performance measures were analyzed as in Study 3, with the exception that end range was not included in this analysis due to the difficulties in interpreting this measure discussed earlier.

Subjective Measures / Questionnaire Data

As in Study 2 and Study 3, immediately after each braking trial, drivers were asked to judge the appropriateness of the FCW system crash alert timing using the 7-point scale ranging from “much too early” to “much too late. These ratings were analyzed for each phase of the study using the same independent variables and analysis approach that was used to analyze the driver performance measures.

In addition, after the Surprise Moving Trial, the alert noticeability questionnaire used in Study 3 was administered to assess what the driver noticed coming on or happening inside the car before they began braking.

3.9.6 Results and Discussion

Overview of Statistical Analysis Approach for Objective Measures

For the analysis of the objective (or performance) measures, an Analysis of Variance (ANOVA) was performed for each relevant performance measure (dependent on whether the lead vehicle was moving or stationary) defined in Table 3-1. Data from the Surprise Moving Trial and Alerted Moving Trials were analyzed separately during the statistical analysis. The criterion set for statistical significance was $p<0.01$ during the analysis of the Alerted Moving Trials, due to the large number of statistical tests carried out (which increases the probability of spuriously significant results, (Hays, 1981)). For the analysis of the Surprise Moving Trial data, the criterion set for statistical significance was $p<0.05$. Unless otherwise noted, all statistically significant results indicated met (and often exceeded) these adopted criterion.

Objective (Or Performance) Measures

Surprise Moving Trial

The between-subjects variables analyzed were crash alert type (Steady HHDD + Non-Speech or Flashing HHDD + Non-Speech), age (younger, middle-aged, or older), and gender (male or female). During 2 of these 24 Surprise Moving Trials, the passenger-side experimenter intervened to assist the driver in coming to a stop. In the one case involving the Steady HHDD + Non-Speech condition, the driver contacted the brake first. In this case, the data obtained at onset of braking was included in the analysis, but any measures obtained throughout or at the end of braking were excluded from the analysis. In the remaining case involving the Flashing HHDD + Non-Speech condition, the passenger-side experimenter contacted the brake first. In this case, none of the data from this trial was included in the analysis. As was mentioned for the two-experimenter intervention cases observed in Study 3, it remains unclear whether these drivers could have avoided impact with the surrogate target without the assistance of the passenger-side experimenter.

As in Study 3, these results did not indicate a main effect of crash alert type (a difference between the Steady HHDD + Non-Speech or Flashing HHDD + Non-Speech conditions) on brake reaction times. The overall mean brake RT was 881 ms, which is 126 ms higher than the mean brake RT found in Study 3 (averaged over these same two crash alert types).

Table 3-39 provides the brake RT distribution (based on 23 RTs) during the Surprise Moving Trials for all drivers. It is worth noting that only two subjects yielded a brake RT higher than the 1.5 second brake RT assumed for crash alert timing purposes. The upper-percentile brake RTs found in Study 3 (see Figure 3-36) are similar to the current data, with nearly identical 85th %tile values, but somewhat higher (0.30 seconds higher) 95th %tile values.

There were no significant main effects of crash alert type. However, there was a Gender x Crash Alert Type interaction for the required deceleration and TTC-Case 1 measures (both measured at

SV braking onset). For the male drivers, the mean required deceleration values for the Steady HHDD + Non-Speech and Flashing HHDD + Non-Speech conditions were -0.40 and -0.33 g's, respectively. For the female drivers, the corresponding mean values were -0.35 and -0.39 g's, respectively. For the TTC-Case 1 measure, for male drivers, the mean values for the Steady HHDD + Non-Speech and Flashing HHDD + Non-Speech conditions were 3.8 and 5.8 seconds, respectively. For the female drivers, the corresponding mean values were 5.1 and 4.4 second, respectively. There was also a Age x Crash Alert Type interaction for the minimum TTC-Case 1 measure. For the younger, middle-aged, and older groups, the mean values for the Steady HHDD + Non-Speech condition were 0.7, 1.9, and 2.0 seconds, respectively. The corresponding mean values for the Flashing HHDD + Non-Speech condition were 1.0, 0.4, and 2.1, respectively. The explanation for these interactions described above are unclear, and in any case, do not distinguish between the two crash alert types investigated.

There were also significant effects of age on TTC-Case 1 at SV braking onset, minimum TTC-Case 1, and peak deceleration throughout braking measure. For the younger, middle-aged, and older age groups, the mean TTC-Case 1 values were 5.9, 4.5, and 4.0 seconds respectively. The corresponding mean minimum TTC-Case 1 values were 0.9, 1.2, and 2.0 seconds, respectively. For the younger, middle-aged, and older age groups, the mean peak deceleration values were -0.52, -0.60, and -0.67 g's, respectively.

In summary, and consistent with Study 3, these objective results did not clearly distinguish between the Steady HHDD + Non-Speech or Flashing HHDD + Non-Speech condition. Overall, the 85th percentile brake RT value during Surprise Moving Trials was nearly identical (within 100 ms) to that observed in Study 2 and Study 3. Across Study 2, Study 3, and the current study (Study 4), 85th percentile brake RT values were 1.21, 1.10, and 1.18 seconds, respectively. However, the 95th percentile brake RT value during Surprise Moving Trials was somewhat higher than observed in previous studies. Across Study 2, Study 3, and the current study (Study 4), 95th percentile brake RT values were 1.38, 1.22, and 1.52 seconds, respectively. For reference and comparison purposes, Table 3-28 provides a list of various percentile values for key variables for this study along with the corresponding values for Study 2 and Study 3 Surprise Moving Trials for comparison purposes (previously shown in Table 3-17 and Table 3-23).

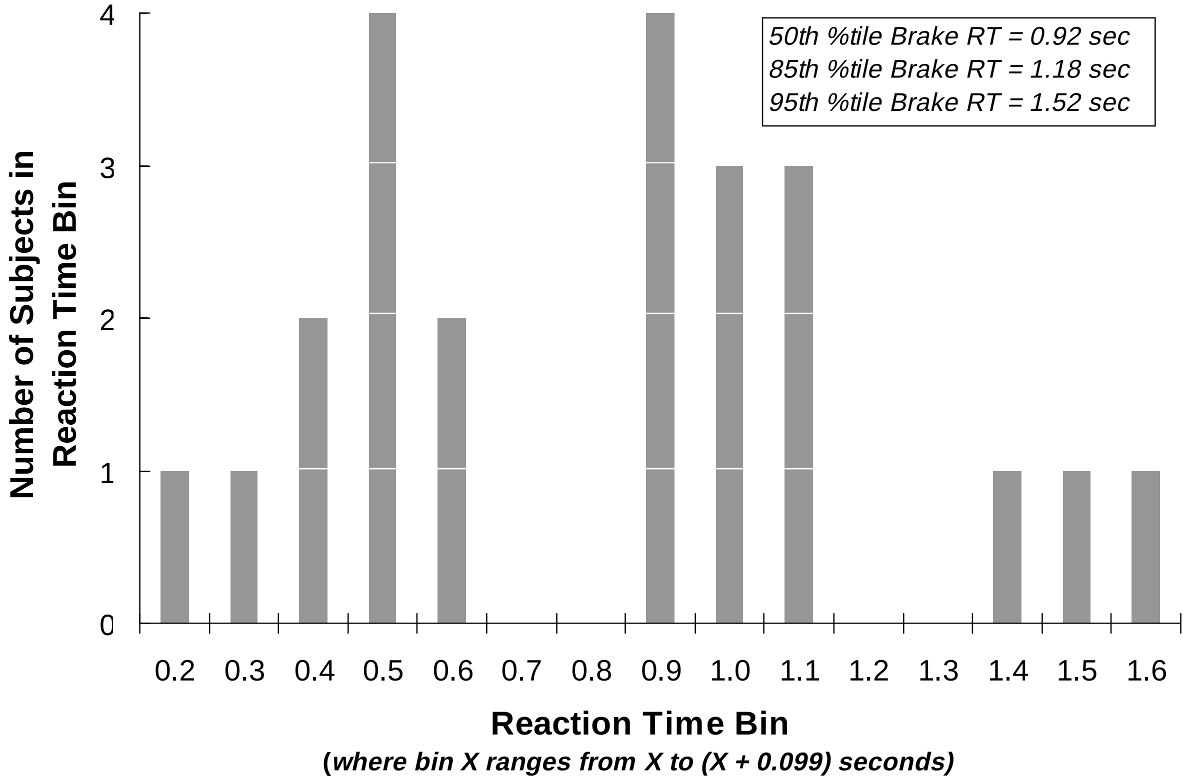


Figure 3-39 Brake Reaction Time Distribution During Surprise Moving Trials (Study 4)

Alerted Moving Trials

The within-subjects variables analyzed were speed (30, 45, and 60 mph), POV braking profile (-0.15, -0.27, or -0.36 g), and repetition (first and second), and the between-drivers variables analyzed were crash alert type (Steady HHDD + Non-Speech or Flashing HHDD + Non-Speech), age (younger, middle-aged, or older), and gender (male or female). Overall, it should be noted that effects involving the variables crash alert type and repetition were largely non-existent in the results reported below.

Results indicated robust main effects of speed and POV braking profile for various performance measures, as well as a robust Speed x Braking Profile interaction for many of these measures. The main effects of speed on variables measured before or at SV braking onset are shown in Table 3-29 and the main effects of speed on variables measured throughout braking are shown in Table 3-30. The main effects of POV braking profile on variables measured before or at SV braking onset are shown in Table 3-31, and the main effects of speed on variables measured throughout braking are shown in Table 3-32. These main effects are provided to help the reader get oriented to the large volume of data analyzed; however, it should be stressed that many of these main effects need to be interpreted in terms of the significant Speed x Braking Profile interactions, which are shown in Table 3-33 and Table 3-34 for variables measured at SV braking onset and variables measured throughout braking, respectively.

The main effects of speed shown in Table 3-29 and Table 3-30 are very systematic and straightforward to interpret. These results indicate that both the SV and POV were very close to the target approach speeds. As speed increased, the following variables increased: range and TTC values (both at SV braking onset and minimum values), minimum headway, required deceleration (albeit very slightly), and brake reaction times. The main effects of POV braking profile shown in Table 3-31 and Table 3-32. As the POV braking profile increased (i.e., the POV braked harder), the following variables *increased*: POV speed, POV deceleration, time headway, range, TTC-Case 1, and required deceleration (all variables listed measured at SV braking onset). In addition, both the actual and peak deceleration values increased as POV braking profile increased. As the POV braking profile increased (i.e., the POV braked harder), the following variables *decreased*: SV deceleration and TTC-Case 2 (both measured at SV braking onset), minimum TTC (both Case 1 and Case 2) and minimum range. In addition, as the POV braking profile increased, both brake RTs and time headway (measured at SV braking onset) somewhat curiously show higher values in the -0.27 g relative to -0.15 and -0.36 g POV braking profile conditions.

As mentioned earlier, many of these main effects of speed and POV braking profile need to be interpreted in terms of the corresponding significant Speed x Braking Profile interactions, which are shown in Table 3-33 for variables measured at SV braking onset, and in Table 3-34 for variables measured throughout braking. At SV braking onset, for the variables listed in Table 3-33, this Speed x Braking Profile interaction indicates that these variables increase with speed (with the exception of the time headway at SV braking onset measure), and that these variables increase with speed at a greater rate in the -0.27 g and -0.36 g POV braking profile conditions (which are very similar, overall) relative to values in the -0.15 g braking profile condition. For nearly all of the variables measured throughout braking, which are shown in Table 3-34 (with the exception of the peak deceleration), nearly the same interaction pattern occurred with the exception that values from the –0.27 g braking profile condition were generally higher than values in the –0.36 g braking profile condition. For the peak deceleration variable, the Speed x Braking Profile interaction (shown Table 3-34) indicated that peak deceleration values increased with speed in a linear fashion in the –0.15 g braking profile condition, remained relatively stable across speed in the –0.27 g braking profile condition, and were higher in the 30 mph relative to the 45 mph and 60 mph conditions.

Table 3-28 Percentile Values for Key Driver Performance Measures During Surprise Moving Trials for Study 4 (Across All Combinations of Age, Gender, and Crash Alert Type Variables)

Time During Which Variable was Measured	Dependent Measure (unit)	15th %tile Value	50th %tile Value	85th %tile Value
At POV Braking Onset	Time Headway (sec)	1.0 *(1.0/1.1)*	1.6 *(1.5/1.6)*	2.2 *(1.9/2.1)*
At SV Braking Onset	Brake Reaction Time (sec)	0.50 *(0.59/0.46)*	0.92 *(0.84/0.82)*	1.18 *(1.23/1.10)*
	Required Deceleration (g)	-0.30 *(-0.28/-0.26)*	-0.38 *(-0.33/-0.32)*	-0.42 *(-0.42/-0.40)*
Throughout Braking	Braking Distance (feet)	78 *(75/86)*	92 *(94/103)*	115 *(105/115)*
	Actual Deceleration (g)	-0.33 *(-0.35/-0.30)*	-0.42 *(-0.42/-0.36)*	-0.47 *(-0.47/-0.44)*
	Peak Deceleration (g)	-0.49 *(-0.53/-0.44)*	-0.59 *(-0.60/-0.55)*	-0.71 *(-0.77/-0.64)*
	Minimum Headway (g)	0.2 *(0.6/0.5)*	0.9 *(1.2/1.3)*	1.6 *(1.6/1.7)*
	Minimum Range (feet)	1 *(5/4)*	10 *(17/15)*	21 *(28/23)*

Note: Numbers shown in parenthesis indicate corresponding values from Study 2 and Study 3 Surprise Moving Trials. Within a set of parenthesis, the left-hand value refers to the corresponding value obtained in Study 2 and the right-hand value refers to the corresponding value obtained in Study 3.

Table 3-29 Significant Main Effects of Speed Condition on Various Driver Performance Measures Analyzed at or Before SV Braking Onset During Alerted Moving Trials (Study 4)

	At POV Braking Onset	At SV Braking Onset							
Speed Condition	**POV Speed (mph)**	**Brake Reaction Time (sec)**	**SV Speed (mph)**	**SV Decel. (g)**	**POV Decel. (g)**	**Range (feet)**	**TTC/ Case 1(sec)**	**TTC/ Case 2(sec)**	**Req. Decel. (g)**
30 mph	30.8	0.499	30.6	-0.02	-0.27	57	3.9	2.3	-0.336
45 mph	45.6	0.547	45.4	-0.03	-0.26	84	4.9	2.8	-0.341
60 mph	60.8	0.578	59.9	-0.04	-0.26	120	5.4	3.3	-0.347

Table 3-30 Significant Main Effects of Speed Condition on Various Driver Performance Measures Analyzed Throughout SV Braking Onset During Alerted Moving Trials (Study 4)

	Throughout Braking				
Speed Condition	Actual POV Decel. (g)	Min. TTC / Case 1 (sec)	Min. TTC / Case 2 (sec)	Min. Time Head-way (sec)	Min. Range (feet)
30 mph	-0.260	1.7	2.1	0.7	13
45 mph	-0.262	2.5	2.7	0.9	22
60 mph	-0.257	3.2	3.2	1.0	37

Table 3-31 Significant Main Effects of POV Braking Profile Condition on Various Driver Performance Measures Analyzed at SV Braking Onset During Alerted Moving Trials (Study 4)

	At SV Braking Onset									
Braking Profile Condition	Brake RT (sec)	SV Speed (mph)	SV Decel. (g)	POV Speed (mph)	POV Decel. (g)	Range (feet)	Time Head-way (sec)	TTC / Case 1 (sec)	TTC / Case 2 (sec)	Req. Decel. (g)
0.15 g	0.515	44.8	-0.031	19.1	-0.15	75	1.2	3.9	3.0	-0.25
0.27 g	0.570	45.6	-0.029	32.3	-0.27	91	1.4	5.2	2.9	-0.35
0.36 g	0.539	45.5	-0.027	43.8	-0.37	95	1.4	5.1	2.6	-0.43

Table 3-32 Significant Main Effects of POV Braking Profile Condition on Various Driver Performance Measures Analyzed Throughout SV Braking Onset During Alerted Moving Trials (Study 4)

	Throughout Braking						
Braking Profile Condition	Actual POV Decel. (g)	Actual Decel. (g)	Peak Decel. (g)	Min. TTC / Case 1 (sec)	Min. TTC / Case 2 (sec)	Min. Time Headway (sec)	Min. Range (feet)
0.15 g	-0.15	-0.30	-0.58	2.8	2.8	0.8	29
0.27 g	-0.27	-0.39	-0.64	2.7	2.8	1.0	16
0.36 g	-0.36	-0.48	-0.74	1.8	2.3	0.8	17

In addition, there were main effects of age on POV speed at POV braking onset, SV speed at SV braking onset, and the peak deceleration measures. For the younger, middle-aged, and older age groups, the mean POV speeds at POV braking onset were 46.1, 45.5, and 45.6 mph, respectively. The corresponding means for mean SV speed at SV braking onset were 45.0, 45.2, and 44.7 mph, respectively. For the younger, middle-aged, and older age groups, the mean peak deceleration values were –0.58, -0.63, and –0.75 g's, respectively. This latter result is consistent with the pattern found across age groups during Surprise Moving Trials.

There were only a few, isolated higher-order interactions beyond the numerous Speed x Braking Profile interactions described above. For the minimum range measure, there was a Gender x Speed interaction. For the male drivers, the mean minimum range for the 30, 45, and 60 mph conditions were 12, 17, and 28 feet, respectively. For the female drivers, the corresponding means were 13, 27, and 45 feet, respectively. For the time headway at POV braking onset measure, there was a (4-way) Age x Gender x Speed x POV Braking Profile interaction. The pattern of results for this measure was very unstable across conditions.

For the POV speed at SV braking onset measure, there was a (4-way) Age x Crash Alert Type x POV Braking Profile interaction x Repetition interaction. Results from the middle-age group appear to be the source of this interaction. For the Flashing HHDD + Non-Speech condition/middle-age group combination, POV speed at SV braking onset decreased as POV deceleration increased. In contrast, for the Steady HHDD + Non-Speech condition/middle-age group combination, POV speed at SV braking onset was similar in the -0.15 and -0.36 g POV braking profile conditions, and lower than the corresponding speeds in the -0.27 g POV braking profile conditions. For the POV actual deceleration measure, there was a (4-way) Age x Crash Alert Type x Speed x Repetition interaction, and a (5-way) Age x Gender x Crash Alert Type x Speed x Repetition interaction. The effects of these interactions were very small, as the mean values for this measure varied between –0.25 to –0.27 g's across all cell combinations of this 5-way interaction.

Table 3-33 Significant Speed x POV Deceleration Profile Interaction Effects for Various Driver Performance Measures Measured at SV Braking Onset During Alerted Moving Trials (Study 4)

Performance Measure at SV Braking Onset	Speed	POV Deceleration Profile -0.15 g	-0.27 g	- 0.36 g
Range (feet)	30 mph	53	60	59
	45 mph	74	87	91
	60 mph	97	127	135
Time Headway (sec)	30 mph	1.2	1.3	1.3
	45 mph	1.1	1.3	1.4
	60 mph	1.1	1.4	1.5
TTC / Case 1 (sec)	30 mph	3.7	4.1	3.9
	45 mph	3.8	5.6	5.3
	60 mph	4.1	5.9	6.1
TTC / Case 2 (sec)	30 mph	2.6	2.3	2.0
	45 mph	2.9	2.9	2.6
	60 mph	3.3	3.5	3.2
POV Speed (mph)	30 mph	20.3	19.0	18.0
	45 mph	31.8	33.3	31.8
	60 mph	43.3	44.9	43.1

Table 3-34 Significant Speed x POV Deceleration Profile Interaction Effects for Various Driver Performance Measures Measured either Throughout or at the End of SV Braking During Alerted Moving Trials (Study 4)

		POV Deceleration Profile		
Performance Measure	**Speed**	**-0.15 g**	**-0.27 g**	**- 0.36 g**
Peak Deceleration (g)	30 mph	-0.54	-0.64	-0.78
	45 mph	-0.59	-0.62	-0.71
	60 mph	-0.63	-0.65	-0.72
Min. Time Headway (sec)	30 mph	0.9	0.8	0.5
	45 mph	0.8	1.0	0.8
	60 mph	0.8	1.1	1.1
Min. TTC / Case 1 (sec)	30 mph	2.6	1.6	0.9
	45 mph	2.8	2.9	1.8
	60 mph	3.1	3.7	2.7
Min. TTC / Case 2 (sec)	30 mph	2.5	2.1	1.6
	45 mph	2.8	2.8	2.3
	60 mph	3.1	3.3	3.1
Min. Range (feet)	30 mph	21	10	6
	45 mph	28	24	14
	60 mph	37	44	30

Comparison of Brake Reaction Times During the Surprise Moving Trial Versus the Alerted Moving Trials Study Phases

This study, relative to Study 2 and Study 3, provided the best opportunity to sensitively compare drivers RTs during surprise, unexpected braking conditions relative to comparable alerted, expected braking conditions. As argued before, it is felt that performance during the (alerted) Follow-On Moving trials in the previous studies may have been impacted by the driver's ability to immediately recover from the Surprise Moving Trial and follow and stay focused on subsequent experimenter instructions. In this study, drivers experienced the "alerted" version of the Surprise Moving Trial (30 mph /-0.36 g POV braking profile) twice in the midst of a set of Alerted Moving Trials, and hence were likely to provide more stable, reliable RT performance. The Surprise Moving Trial: Alerted Moving Trial RT ratio was 1.8, 2.6, 3.3, and with respect to the 50th, 85th, and 95th percentile RT values for these two study phases. These ratios may have potential future use for conditions under which a surprise, unexpected braking event is not feasible. It is also worth noting note that the spread of driver RTs between the 15th percentile and 85th percentile values was 3.8 times higher during the Surprise Moving Trial relative to that observed during the corresponding "alerted" version of this trial during Alerted Moving Trials.

Subjective Measures / Questionnaire Data

Crash Alert Timing Ratings

<u>Surprise Moving Trial</u>

The between-subjects variables analyzed were crash alert type (Steady HHDD + Non-Speech or Flashing HHDD + Non-Speech), age (younger, middle-aged, or older), and gender (male or female). Once again, in this study phase, the RDP crash alert timing was used. Results indicated no statistically significant effects, with an overall rating of 4.4 (closest to "just right"). The histogram provided in Figure 3-40 shows the percent of timing responses at each point along the crash rating scale. Across all drivers, 23 total ratings were made. This data indicates that 61%, 35%, and 4% of the timing responses were "just right", "slightly late", "moderately late", respectively.

Relative to the crash alert timing ratings obtained during Surprise Moving Trials in Study 2 and Study 3, drivers in this study rated the alert to have occurred later on the crash alert timing scale (compare Figure 3-40 to both Figure 3-34 and Figure 3-37). However, all but one of the ratings in this study were either "just right" or slightly late". This difference in timing ratings across studies may be attributable to the slower overall brake RTs obtained in the this study relative to those found during Surprise Moving Trials in Study 2 and Study 3.

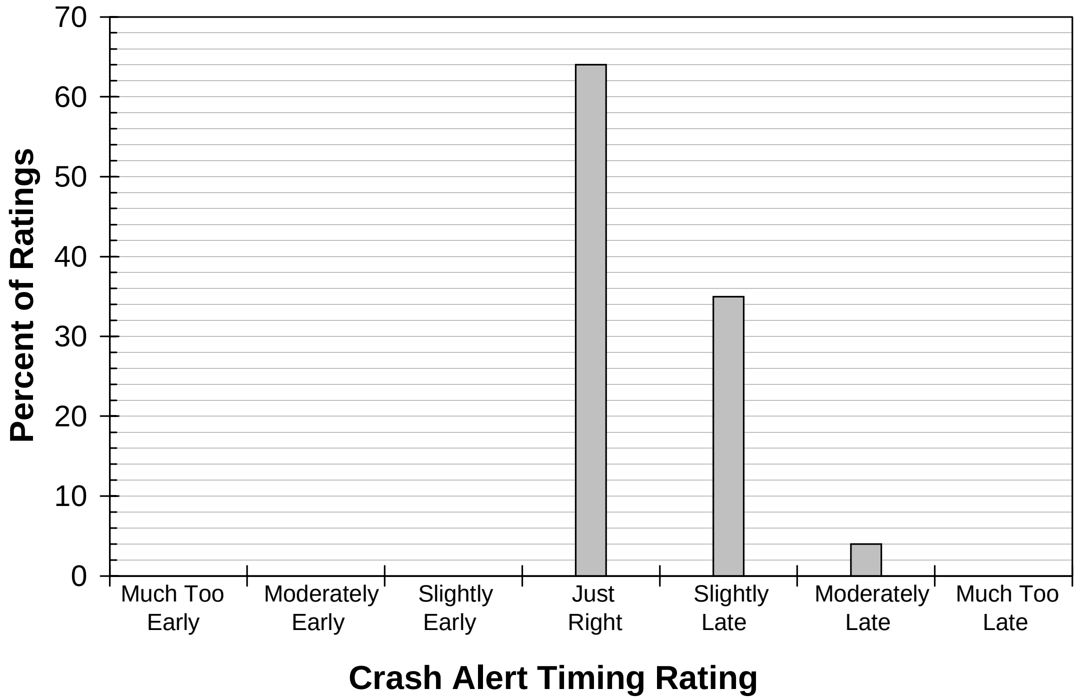


Figure 3-40 Histogram of Subjective Crash Alert Timing Ratings During Surprise Moving Trials (Study 4)

<u>Alerted Moving Trials</u>

The within-subjects variables analyzed were speed (30, 45, and 60 mph), POV braking profile (-0.15, -0.27, or -0.36 g), and repetition (first and second), and the between-drivers variables analyzed were crash alert type (Steady HHDD + Non-Speech or Flashing HHDD + Non-Speech), age (younger, middle-aged, or older), and gender (male or female). In the 30, 45, and 60 mph conditions, mean crash alert timing ratings were 4.8, 4.5, and 4.3, respectively. In the -0.15, -0.28, and -0.36 g POV braking profile conditions, mean crash alert timing ratings were 4.8, 4.3 and 4.5, respectively. However, these main effects need to be interpreted in terms of the Speed x Braking Profile interaction. This interaction indicated that the mean crash alert timing ratings in the -0.15 g braking profile condition were relatively stable across speeds (mean rating ranging from 4.7 - 4.8), whereas the ratings at the two higher braking profile conditions decreased (i.e., were judged “earlier”) as speeds increased. In the -0.27 g braking profile condition, mean crash alert timing ratings at the 30, 45, and 60 mph conditions were 4.6, 4.2, and 4.0, respectively. In the -0.36 g braking profile condition, mean crash alert timing ratings at the 30, 45, and 60 mph conditions were 5.0, 4.3, and 4.0, respectively. Hence, the difference between these two higher braking profile conditions was primarily restricted to the 30 mph condition.

A more insightful look at these crash alert timing data is provided in Figure 3-41. This figure shows the percent of timing responses at each point along the crash rating scale as a function of each Speed x Braking Profile combination. (For each combination, across all drivers, 48 total ratings were made). This figure averages over the independent variables of repetition, crash alert type, age, and gender. For comparison purposes, results from Study 2 found with Alerted Stationary Trials are also provided in Figure 3-41. (For each of the two approach speed conditions during these latter trials, across all drivers, 96 total ratings were made). On the one hand, there were very few “much too early” and “moderately early” ratings across all Speed/POV Braking Profile combinations during the Alerted Moving Trials. On the other hand, there were 6 Speed/POV Braking Profile combinations during these trials in which the percent of combined “moderately late” and “much too late” responses ranged between about 15%-25%. As can be seen in Figure 3-41, 3 of these 6 combinations involved the 30 mph condition in which the lead vehicle was moving, and 3 of these 6 combinations occurred when the POV braking profile was -0.15 g’s.

Overall, as can be seen in Figure 3-41, the crash alert timing ratings found during the Alerted Moving Trials in this study were judged as “later” on the crash alert timing rating scale relative to those obtained during the Alerted Stationary Trials in Study 2. This rating difference may be due to the relatively greater uncertainty for the driver surrounding the behavior of the surrogate target (lead vehicle) during Alerted Moving Trials relative to Alerted Stationary Trials. In the former case, the lead vehicle could brake at various levels, whereas in the latter case, the surrogate target was parked.

Summary of Crash Alert Timing Ratings Findings

In summary, these crash alert timing ratings are generally consistent with those found in the previous Study 2 and Study 3, and provide further evidence that the crash alert timing approach directly derived/modeling from the CAMP Study 1 findings (i.e., the RDP crash alert timing) does an excellent job from a driver preference perspective under a wide range of driver expectancy and kinematic conditions. Furthermore, it should be kept in mind that for the Speed/POV Braking Profile combinations discussed above in which 15%-25% of the drivers rated the alert as either “moderately late” or “much too late”, drivers were still able to avoid colliding with the surrogate target.

It is also interesting to compare the crash alert timing ratings in this study found during Surprise Moving Trials to those found under identical POV speed/POV braking profile conditions (30 mph /-0.36 g) during Alerted Moving Trials (see Figure 3-40 and Figure 3-41). The mean crash alert timing rating during the Surprise Moving Trial and the alerted version of this trial were 4.4 and 5.0, respectively. It should be noted that the assumed driver RT (which was input into the RBD crash alert timing algorithm) was about 1 second less during the Alerted Moving Trial.

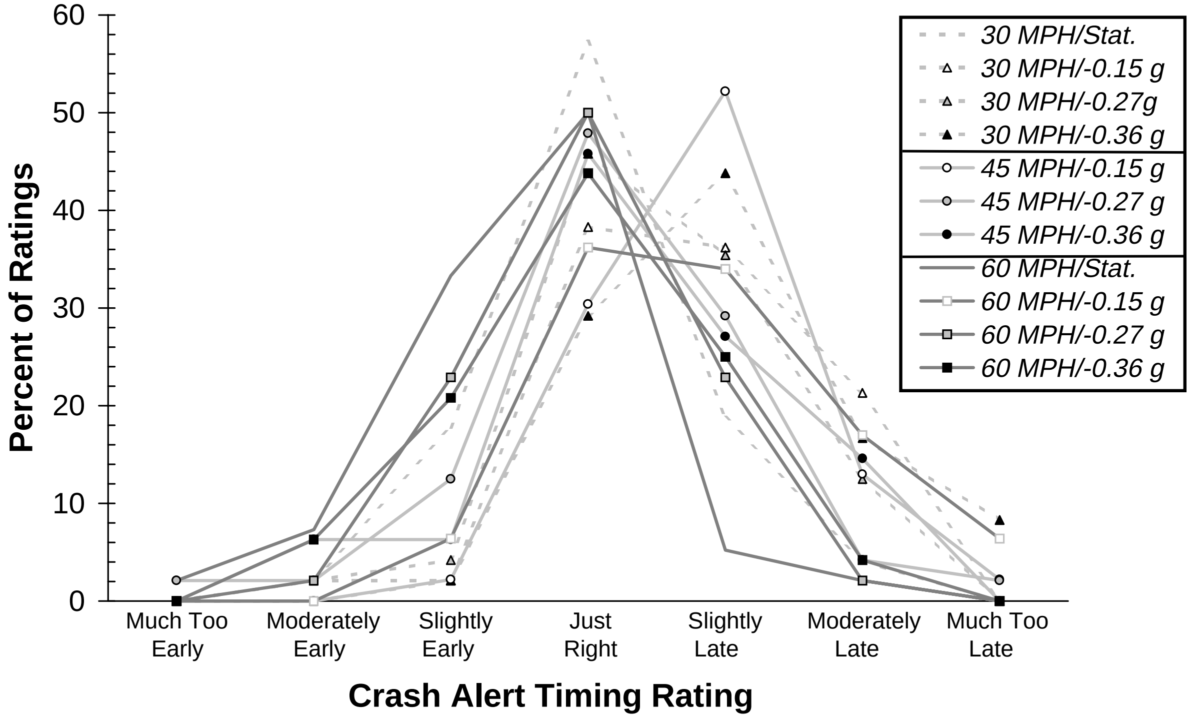


Figure 3-41 Percent of Crash Alert Timing Ratings with the RDP Crash Alert Timing Approach During Alerted Moving Trials (Study 4) and Alerted Stationary Trials (Study 2) Across All Speed/POV Braking Profile Combinations Tested

Alert Noticeability Questionnaire

Results from this questionnaire (administered immediately after the Surprise Moving Trial) are shown in Table 3-35, along with results from Study 3 for comparison purposes (previously shown in Table 3-25). The identical criterion for "noticeability" employed in Study 3 across the various crash alert modality components was employed in the current study. Across both alert types evaluated in this study (Steady HHDD + Non-Speech, Flashing HHDD + Non-Speech), the non-speech component of the alert was noticed by all drivers. In contrast, as in Study 3, the noticeability of the visual alerts varied considerably across these two crash alert types. In the Steady HHDD + Non-Speech and the Flashing HHDD + Non-Speech conditions, the visual alerts were noticed by 4 of 12 drivers and 10 of 12 drivers, respectively. These results are very consistent with those found in Study 3, and hence, the change in the surprise trial technique from Study 3 to Study 4 had no substantial impact on the pattern of alert noticeability results across crash alert types. For the interested reader, a more detailed breakdown of these data beyond the high-level "noticeability" criterion is provided in Appendix A17.

The visual alert data from this study and Study 3 suggest that flashing the HHDD may be prudent in order to improve the noticeability of the HHDD (which may also be true for the HUD), particularly when this alert is coupled only with an auditory crash alert since some drivers may not hear the auditory alert under some conditions. Once again, it should be noted that under more typical conditions in which the driver would be aware his/her vehicle was equipped with a visual crash alert, the probability of noticing these visual alerts may increase.

Table 3-35 Noticeability of Visual and Auditory Alerts Across the "Flashing HHDD+Non-Speech" and "Steady HHDD+ Non-Speech" Crash Alert Types (Studies 4 and 3)

Crash Alert Type	Visual Alert Noticed?	Auditory Alert Noticed?
Flashing HHDD + Non-Speech	10/12 (*8/12*)	12/12 (*12/12*)
Steady HHDD + Non-Speech	4/12 (*5/12*)	12/12 (*12/12*)

Note: Numbers shown in parentheses indicate corresponding values from Study 3, Surprise Moving Trials.

3.9.7 Follow-up Analysis on Brake Reaction Time Findings

A better understanding of these brake RT results was attained by conducting a frame-by-frame video analysis of the driver's eye position at alert onset, and observing any subsequent eye movements made to the visual alert (prior to and after braking onset). The relationship of these eye movement patterns to both visual alert noticeability and brake RT measures were then explored, to the extent that was possible given the limited data set. This analysis is shown in Table 3-36. Corresponding results from Study 3 are also shown in this table (in smaller, italicized font), which follow the same pattern as those reported below.

Table 3-36 Detailed Gaze Location, Eye Movement, and Visual Alert Noticeability Analysis for the "Steady HHDD + Non-Speech" and "Flashing HHDD + Non-Speech" Crash Alert Types for Study 4 Data and Corresponding Study 3 Data (Data from this latter study in indicated in italicized, smaller font)

Gaze location of driver at alert onset / Number of drivers at gaze location at alert onset	**Crash Alert Type / Number of drivers at gaze location at alert onset with this Crash Alert Type**	**Number of drivers who noticed visual alert / Number of possible drivers in Gaze Location x Crash Alert Type cell**	**Number of drivers who…**			**Number of drivers who noticed visual alert without pausing to look at the alert / Number of possible drivers in Gaze Location x Crash Alert Type cell who did not pause to took at alert**
			…paused to look at visual alert *prior to braking* / Number of possible drivers in Gaze Location x Crash Alert Type cell	… paused to look at visual alert *after braking* / Number of possible drivers in Gaze Location x Crash Alert Type cell	…did not pause to look at visual alert / Number of possible drivers in Gaze Location x Crash Alert Type cell	
Forward Scene / n=7 *(n=19)*	Steady HHDD + Non-Speech / n=3 *(n=11)*	1 / 3 *(5 / 11)*	0 / 3 *(1 / 11)*	1 / 3 *(2 / 11)*	2 / 3 *(8 / 11)*	0 / 2 *(2 / 8)*
	Flashing HHDD + Non-Speech / n=4 *(n=8)*	4 / 4 *(5 / 8)*	0 / 4 *(1 / 8)*	2 / 4 *(3 / 8)*	2 / 4 *(4 / 8)*	2 / 2 *(5 / 8)*
Conventional Instrument Panel / n=12	Steady HHDD + Non-Speech / n=6	0 / 6	0 / 6	0 / 6	6 / 6	0 / 6
	Flashing HHDD + Non-Speech / n=6	4 / 6	2 / 6	0 / 6	4 / 6	2 / 4

Note: Only subjects for whom the location of their gaze immediately prior to alert could be scored as either at the forward scene or at the conventional (head-down) instrument panel location were included in this analysis. For both Study 4 and Study 3, this meant 5 of the 24 subjects (12 possible subjects per crash alert type) were excluded from this analysis. Note that there was no compelling reason to look down in Study 3 during the Surprise Moving Trial, and hence, the Study 3 data is concentrated for cases where gaze location at alert onset was the forward scene.

Table 3-37 Individual Brake Reaction Times for Drivers Who Were Gazing at Either the Conventional Instrument Panel or Forward Scene at Crash Alert Onset as a Function of Crash Alert Type and Age Group (With Gender also Indicated)

		Driver Gaze Location at Alert Onset	
Crash Alert Type	**Age Group**	**Conventional Instrument Panel**	**Forward Scene**
Steady HHDD + Non-Speech	Young		0.49 (female) 0.52 (female)
	Middle-Aged	0.99 (female) 1.09 (male) 1.15 (male)	
	Older	0.55 (male) 1.15 (male) 0.95 (female)	0.32 (female)
Flashing HHDD + Non-Speech	Young		0.52 (male) 0.45 (female) 0.65 (male) 0.55 (female)
	Middle-Aged	1.52 (female) 1.69 (female)	
	Older	1.02 (female) 0.62 (male) 0.92 (female)	

Note: * Denotes subject who paused to look at the visual alert prior to braking. Both of these subjects avoided impacting the surrogate (lead vehicle) target without braking intervention from the passenger-side experimenter.

First, driver's eye position at alert onset was scored and placed into various gaze location categories. As can be seen in the first column of Table 3-36, 7 and 12 drivers were categorized into the "forward scene" and (head-down) "conventional instrument panel" categories, respectively. (Five drivers from this study were excluded from this analysis. Three drivers could not be scored due to either poor image quality or eye closure at alert onset, one driver was looking at the rear-view mirror at alert onset, and one driver happened to be looking at the HHDD at alert onset.) Hence, despite the experimenters' best attempts during these Surprise Moving Trials to time the crash alert to occur when the driver was looking down at the conventional instrument panel, about 1/3 of the drivers happened to be looking at the forward scene when the alert was presented. This is not surprising given that drivers do not typically make long, sustained visual fixations to the instrument panel, and instead typically opt for making a series of relatively short head-down visual fixations to perform an in-vehicle task. Between these fixations, drivers typically visually check (i.e., fixate) the forward scene.

Finally, it should be noted there was a strong age effect associated with the driver gaze location at brake onset (which can be seen in Table 3-37, described below). Six of the 7 drivers who were looking at the forward scene at crash alert onset were younger-aged drivers. In sharp contrast, all of the 11 drivers who were looking at the conventional instrument panel at crash alert onset were either middle-aged or older-age drivers. Hence, for reasons that are somewhat unclear, a much higher degree of success was attained with getting middle-aged and older-aged drivers in terms of getting them to look at the conventional instrument panel at alert onset. As a consequence, any comparisons between brake RT as a function of driver gaze location are necessarily confounded by driver age effects.

As can be seen in the second column of Table 3-36, these 7 “forward scene” and 12 “conventional instrument panel” gaze locations at alert onset are further broken down as a function of crash alert type (Steady HHDD + Non-Speech versus Flashing HHDD + Non-Speech). Fortunately, there are nearly an equal number of drivers for each crash alert type within each gaze location at alert onset category (forward scene versus conventional IP), which allows one to better explore the effects of crash alert type as a function of gaze location of the driver at alert onset.

As can be seen in the third column of Table 3-36, independent of driver’s gaze location at alert onset, it appears the probability of the driver noticing the visual alert is much higher for the Flashing HHDD + Non-Speech condition. This same trend was true for the Study 3 results, particularly if one includes drivers who were not looking in these two gaze location categories at alert onset (see Table 3-25).

Columns four through six of Table 3-36 indicate the number of drivers who paused to look at the visual alert *prior to braking* (column four), the number of drivers who paused to look at the visual alert *after braking* (column five), and the number of drivers who did not pause to look at the visual alert (column six). These data indicate that the two drivers who looked at the visual alert prior to braking were looking at the conventional instrument panel at the onset of the Flashing HHDD + Non-Speech alert. Furthermore, these two drivers (both middle-aged females) experienced the two longest brake RTs (1.52 and 1.69 seconds) in Study 4. Table 3-37 provides each subject’s brake RT in this analysis as a function of crash alert type and gaze location at alert onset. These limited data suggest *any* RT slowing effects caused by the Flashing HHDD + Non-Speech alert are due to actually pausing to look at the visual alert, rather than the due to flashing *per se*. For the case in which drivers were looking at the conventional instrument panel at the onset of the alert, and who did not fixate the alert prior to braking, there does not appear to be any difference in RT between the Steady HHDD + Non-Speech and Flashing HHDD + Non-Speech conditions with the available data. A similar “non-difference” between these crash alert types can be observed for the young drivers who were looking forward at the onset of the alert. These isolated brake RT slowing effects which are *potentially* due to pausing to look at the visual alert prior to braking onset need to put into the following context.

First, for these two drivers (as was true for all 19 drivers in this analysis), it was their first experience with the crash alert. Under more typical conditions, the driver would be aware his/her vehicle was equipped with a visual crash alert. The current experimental conditions in all likelihood increased any novel tendency drivers may have to choose to pause and look at the visual alert prior to braking. It seems likely that under the more typical conditions described above, drivers would not choose to pause to look at the alert (in part because of the compelling nature of rapidly approaching a vehicle ahead), and would be more capable of “peripherally” using the information provided by the location and flashing nature of this visual indicator without a direct fixation. Indeed, of the four remaining “novice” drivers who were also looking at the conventional instrument panel at the onset of the Flashing HHDD + Non-Speech alert, two of these drivers did not pause to look at the visual alert, and two of the drivers noticed the visual alert during this first experience without actually pausing to look at the alert.

Second, both of the two drivers mentioned above were still able to avoid impact with surrogate target without braking intervention by the passenger-side experimenter. Furthermore, this was also true for both drivers in Study 3 who paused to look at the visual alert prior to braking (see Table 3-36, column 4), who were both looking at the forward scene at crash alert onset. It remains unclear whether the brake RTs may have been actually slower or faster for these particular Study 4 and Study 3 drivers if they had experienced the Steady HHDD + Non-Speech alert (or no visual alert at all). Indeed, the flashing HHDD may have played a critical role in allowing these drivers to successfully avoid impacting the target by orienting the driver’s visual attention from the in-vehicle visual search task to the road ahead.

Third, as can be seen in the rightmost column of Table 3-36, given that drivers did not pause to look at the alert, 0 of the 8 possible drivers experiencing the Steady HHDD + Non-Speech alert noticed the visual alert, and 4 of the 6 possible drivers experiencing the Flashing HHDD + Non-Speech alert noticed the visual alert. The corresponding data from Study 3 were as follows. Given that drivers did not pause to look at the alert, 2 of the 8 possible drivers experiencing the Steady HHDD + Non-Speech alert noticed the visual alert, and 5 of the 8 possible drivers experiencing the Flashing HHDD + Non-Speech alert noticed the visual alert. Clearly, together with the data reported above, this limited data set clearly indicate that the likelihood of noticing and fixating the telltale is substantially higher in the Flashing HHDD + Non-Speech condition. Furthermore, the likelihood of noticing the telltale without actually pausing to look at the telltale is substantially higher in the Flashing HHDD + Non-Speech condition. Clearly, in terms of accommodating drivers who may not hear the alert sound (either due to hearing impairments and/or competing noises) and potentially facilitating these drivers to look away from inside of the vehicle and toward the forward scene, these limited data provide support for using a Flashing versus Steady HHDD.

Fourth, for drivers who were looking at the forward scene at alert onset, none of the four drivers in the Flashing HHDD + Non-Speech in Study 4 paused to look at the visual alert. For the Study 3 drivers who were looking at the forward scene at alert onset, only 1 of the 8 drivers in the Flashing HHDD + Non-Speech condition paused to look at the visual alert. As is pointed out in Chapter 2 of this report, the percent of rear-end collisions which can be attributed to drivers looking head-down while performing an in-vehicle task appears to be relatively small compared to the percent of rear-end collisions which can be attributed to drivers become inattentive for a non-compelling reason (e.g., daydreaming). Furthermore, once again, neither of the two drivers who were looking head-down while performing the in-vehicle (visual search) task, and who *may* have experienced RT slowing due to pausing to look at the alert, needed braking assistance from the passenger-side experimenter to avoid colliding with the surrogate (lead vehicle) target.

In summary, these data suggest that a flashing HHDD visual crash alert is more likely to be noticed than steady HHDD visual crash alert, even when the driver does not actually pause to look at the visual telltale. Clearly, in terms of accommodating drivers who may not hear the alert sound either due to hearing impairments and/or competing noises, and potentially facilitating these drivers to look away from inside of the vehicle and toward the forward scene, these limited data provide support for using a Flashing versus Steady HHDD. Furthermore, any potential brake RT slowing effect experienced by a relatively limited number of drivers in this study is hypothesized to be due to a novelty effect. Assuming this slowing effect occurred, the drivers who paused to look at the visual alert prior to braking were still able to avoid the impact with the surrogate target without braking intervention by the passenger-side experimenter. Indeed, the flashing HHDD may have played a critical role in allowing these drivers to avoid impact by orienting the driver's visual attention from the in-vehicle visual search task to the forward scene ahead. Finally, even if the brake RT slowing effect mentioned above occurred, this phenomenon appears to limited to when the driver was looking at the conventional instrument panel (as opposed to the forward scene) prior to braking onset. The percent of rear-end collisions which can be attributed to drivers looking head-down while performing an in-vehicle task is relatively small compared to the percent of rear-end collisions which can be attributed to drivers who are looking at the forward scene and become inattentive for a non-compelling reason.

3.10 Comparison of Driver Performance With a Crash Alert Versus Without a Crash Alert Under Alerted Conditions

In both Study 2 and Study 4, all drivers had previously participated in Study 1 (although no drivers participated in both Study 2 and Study 4). Hence, driver's braking behavior with a crash alert during both Study 2-Alerted Stationary Trials and Study 4-Alerted Moving Trials could be compared to previous data obtained under nearly the same conditions without a crash alert for the same driver (Study 1). (Recall, during alerted trials, the driver is asked to brake in response to the anticipated alert.) It should be noted that this comparison is more straightforward with respect to Alerted Stationary Trials, since drivers were more likely to be closer to the exact same conditions with a crash alert (Study 2) versus without a crash alert (Study 1) than under Alerted Moving Trials. In the latter case, the time headways prior to the lead vehicle braking introduce inherent variability in the timing of the crash alert onset, and subsequent braking onset by the driver. Furthermore, since the Steady HHDD + Non-Speech and the RDP crash alert timing were the only crash alert type and timing conditions that were used in both Study 2 and Study 4, data from this combination of conditions was examined so that unconfounded comparisons could be made across Alerted Stationary Trials and Alerted Moving Trials relative to the corresponding baseline (Study 1) trials. Finally, since the main interest here is in driver performance with versus without crash alerts under alerted conditions, only statistically significant effects involving alert presence (i.e., Study) effects will be discussed below.

3.10.1 Alerted Stationary Trials - With Versus Without a Crash Alert

In this comparison of driver behavior with versus without a crash alert under alerted conditions, drivers were selected who had participated in both Study 2 and Study 1. An Analysis of Variance (ANOVA) was performed for each of the following measures: SV speed at SV braking onset, SV acceleration at SV braking onset, range at SV braking onset, required deceleration at SV braking onset, actual deceleration, peak deceleration, minimum TTC-Case 1, and minimum range. Each of these measures were previously defined in Table 3-3. The criterion set for statistical significance was $p<0.01$. Unless otherwise noted, all statistically significant results indicated met (and often exceeded) these adopted criterion. The within-subjects variables analyzed were Study/Alert Presence (Study 1/no crash alert, Study 2/"Steady HHDD + Non-Speech" alert) and (approach) speed (30 and 60 mph), and the between-subjects variables analyzed were age (younger, middle-aged, or older) and gender (male or female).

Results indicated main effects of alert presence on SV acceleration at SV braking onset, required deceleration at SV braking onset, actual deceleration, and peak deceleration. These main effects are shown in Table 3-38. The results for the SV acceleration at SV braking onset are due to drivers sometimes hovering over the brake during "last-second" braking judgments in CAMP Study 1, whereas drivers in Study 2 braked in "crisp", firm manner in response to the alert. The results for the remaining main effects indicate that with the alert present, drivers were attaining shorter braking distances (higher actual decelerations), using more controlled braking (lower peak decelerations). With respect to the latter "controlled braking" finding, a significant Alert Presence x Speed interaction suggests this effect was more prominent in the 30 mph condition. In the 30 mph condition, the mean peak decelerations in Study 1 (no alert) and Study 2 (alert present) were –0.82 and –0.60, respectively. In the 60 mph condition, the corresponding means were –0.85 and –0.72, respectively. The interpretation of these effects is not straightforward. On one hand, one could argue that the presence of the alert resulted in a "more controlled" braking profile, which would be beneficial under certain conditions. However, another possibility, which cannot be ruled out, is this pattern of results is due to a practice effect, since Study 1 was completed before Study 2, and drivers may have felt more comfortable braking the test vehicle and whole experimental set-up in the latter study.

3.10.2 Alerted Moving Trials - With Versus Without a Crash Alert

In this comparison of driver behavior with versus without a crash alert under alerted conditions, drivers were selected who had participated in the both the Study 4-"Steady HHDD + Non-Speech" crash alert type condition and Study 1. An Analysis of Variance (ANOVA) was performed for each of the following measures: time headway at POV braking onset, SV speed at SV braking onset, SV acceleration at SV braking onset, range at SV braking onset, required deceleration at SV braking onset, actual deceleration, peak deceleration, minimum TTC-Case 2, minimum TTC-Case 2, minimum headway, and minimum range. Each of these measures was previously defined in Table 3-3. The criterion set for statistical significance was $p<0.01$. Unless otherwise noted, all statistically significant results indicated met (and often exceeded) these adopted criterion.

The within-subjects variables analyzed were Study/Alert Presence (Study 1-no crash alert, Study 4-"Steady HHDD + Non-Speech" alert), speed (30, 45, and 60 mph), and POV braking profile (light, moderate, hard), and the between-subjects variables analyzed age (younger, middle-aged, or older), and gender (male or female). With respect to POV braking profile, there is somewhat of a confound between Study 1 and Study 4, which will be revisited in the reporting of these results. In the former study, the three POV braking profiles were -015, -0.28, and -0.39 g's. In the former study, the three corresponding POV braking profiles were -015, -0.27, and -0.36 g's.

Results indicated main effects of alert presence on SV speed at SV braking onset, SV acceleration at SV braking onset, and peak deceleration. These main effects are shown in Table 3-39. Once again, as explained above, the results for the SV acceleration at SV braking onset are artifactual in nature. The results for the remaining main effects indicate that with the alert present, drivers were at slightly higher speeds (1 mph difference across studies), and using more controlled braking (lower peak decelerations). As mentioned above, one could argue that the presence of the alert resulted in a "more controlled" braking profile, which would be beneficial under certain conditions. However, another possibility is that this pattern of results is once again due to a practice effect, since Study 1 was completed before Study 4.

3.10.3 Summary of "With" Versus "Without" Crash Alert Comparison

Overall, during these expected braking conditions, these results suggest that, relative to drivers without a crash alert, drivers with a crash alert reached lower peak decelerations without extending their braking distances. In remains unclear whether this effect is due to the presence of the alert or to a practice effect, since all drivers participated in the baseline study (Study 1-no alert) prior to a study where they experienced a crash alert (Study 2 or Study 4).

Table 3-38 Significant Main Effects of Study (Alert Presence) on Various Variables Measured at SV Braking Onset During Alerted Stationary Trials (Comparison of Study 1 Versus Study 2 Results)

Study/Alert Presence	Mean Current Dec. (g)	Mean Required Dec. (g)	Mean Actual Dec. (g)	Mean Peak Dec. (g)
Study 1/Without Alert	-0.05	-0.33	-0.40	-0.84
Study 2/With Alert	-0.03	-0.37	-0.48	-0.66

Table 3-39 Significant Main Effects of Study (Alert Presence) on Various Variables Measured at SV Braking Onset During Alerted Moving Trials (Comparison of Study 1 Versus Study 4 Results)

Study/Alert Presence	Mean SV Speed (mph)	Mean Current Dec. (g)	Mean Peak Dec.(sec)
Study 1/Without Alert	44.4	-0.05	-0.86
Study 4/With Alert	45.3	-0.03	-0.67

3.11 General Discussion

Results indicated differences in both objective (performance) data and subjective (questionnaire-oriented) data across the crash alert types examined. It should be stressed that each of the crash alert modality components of the crash alert types tested were chosen to represent realistic production constraints (e.g., the direct view high head-down display could not be placed higher and more central in the driver's field of view without interfering with a short driver's view of the road), and were well-received by the drivers. The key findings with respect to crash alert modality effects were as follows.

First, the crash alert types including a non-speech tone component resulted in faster brake RTs relative to the crash alert type including a speech component. It should be stressed this RT effect was observed under expected braking conditions during which drivers were experienced with the various crash alert types, as well as under unexpected braking event (Surprise Moving Trials) conditions during which drivers were completely unaware the vehicle was equipped with a FCW system. Together, these data provide compelling evidence against the use of speech crash alerts.

Second, drivers rated the crash alert types including either a speech or brake pulse component as more annoying relative to the remaining crash alert types, under the assumption that FCW system crash alerts would occur in non-threatening situations between once a day to once a week. Driver annoyance is an extremely important consideration in terms of driver acceptance, particularly in the initial introduction of FCW systems.

Third, the brake pulse alert provided a "vehicle slowing" advantage during the delay time interval (i.e., between when the crash alert timing was violated and when the driver braked). Thus, under some conditions, the driver was in a more conservative kinematic scenario at braking onset in the crash alert type condition including a brake pulse component. Furthermore, adding a non-speech tone component to the brake pulse alert significantly reduced the relatively slow brake RTs initially observed in the HHDD + Brake Pulse condition (to remind the reader, HHDD refers to the High Head-Down Display). However, unlike the visual and auditory alerts examined here, there are important unresolved implementation and driver behavior issues surrounding the brake pulse 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. It should be noted that these concerns are equally true for other (relatively immature) haptic alerts which have been suggested. These alerts include accelerator pedal pushback, steering wheel vibration, and seat vibration. If these issues surrounding the brake pulse could be satisfactorily resolved, these exploratory results suggest that the "vehicle slowing" advantage might be beneficial, and that the brake pulse should be "explained" by coupling it with an auditory and visual alert component. Furthermore, it appears the brake pulse cue as implemented in the human factors studies reported in Chapter 3 would be a reasonable candidate for a specific brake pulse implementation.

Fourth, although there were no performance differences associated with the relevant HHDD versus HUD comparisons, subjects indicated a strong preference for the head-up display (or HUD). In a related finding, for a 1-stage crash alert approach, drivers indicated a strong preference for a multi-modality alert approach (particularly a dual-modality crash alert) over a single-modality crash alert approach. Although a dual-modality crash alert approach is supported in terms of accommodating driver preferences, it should be noted the possibility exists that drivers' lack of experience with single-modality alerts may have influenced the observed pattern of driver preferences.

Fifth, after the surprise braking event was experienced by naive drivers, nearly all drivers reported noticing non-speech tone, speech, and brake pulse components of these crash alert types examined, and significantly more drivers noticed the Flashing HHDD and steady HUD relative to the steady HHDD. It should be stressed that each of these drivers were completely unaware the vehicle was equipped with a FCW system crash alert during the testing phase in which the crash alert was first experienced. This data provides direct evidence that the auditory alerts and brake pulse profile established during pilot testing met the goal of providing an alert that would be clearly noticed by naive drivers. In addition, overall, about 3 of 4 subjects indicated that the radio should be muted during the 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.

The drivers' ability to notice the visual alerts under surprise conditions varied considerably across the crash alert types. However, it should be stressed that these visual alert noticeability results should be treated somewhat cautiously, since under more typical conditions in which the driver would be aware his/her vehicle was equipped with a visual crash alert, the probability of noticing these visual alerts may increase substantially. Given this caveat, data suggested that flashing the HHDD may be prudent in order to improve the noticeability of the HHDD (which may also be true for a flashing HUD, which was not examined here). This would be particularly true when this alert is coupled only with an auditory crash alert, since some drivers 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. Additional important reasons for including a visual alert modality component in any FCW crash alert modality approach 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 auditory or brake pulse crash alert components 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.

In addition to these crash alert modality effects, there were also key findings with respect to developing a crash alert timing approach. First, brake RTs observed under the surprise technique resulting in the highest upper percentile values (i.e., the Study 4 head-down visual search task), yielded 85^{th} and 95^{th} percentile (i.e., slower) RTs of 1.2 and 1.5 seconds, respectively. These values are being considered for the assumed driver brake RT in response to the crash alert during the development of crash alert timing requirements for the minimum crash alert timing setting (i.e., latest, most aggressive setting for a FCW system.). 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). Johansson and Rumar (1971) measured 5 driver's brake reaction times to an auditory stimulus (a "buzzer") which was implemented in the driver's own personal vehicle. Four of these drivers were between 25 and 35 years old, and the fifth driver was 50 years old. This buzzer was presented a total of 10 times at random intervals during their normal driving. The interval between buzzer presentations ranged between 1 hour and "more than a week". Drivers were instructed to immediately respond to the buzzer by tapping the brake pedal (without bringing the car to a stop). The first three stimulus presentations were considered practice, and were not reported or included in the driver brake RT analysis. The obtained driver brake reaction times ranged between 0.5 and 1.1 seconds. Olson and Sivak (1986) measured 64 drivers' brake RTs to a 6-inch high by 3-foot wide yellow foam object encountered after cresting a hill on a 2-lane public road. These drivers were led to believe that the purpose of their drive was to become familiar with the route for a study conducted the following day. 49 of these drivers were between 18 and 40 years old, and 15 of these drivers were between 50 and 84 years old. Observed 85th and 95th percentile driver brake reaction times to the obstacle were about 1.3 and 1.6 seconds, respectively. The slightly faster (100 ms faster) upper percentile driver brake RTs obtained in the current study compared to the Olson and Sivak (1986) study may be due to several factors, including drivers associating increased crash risk with the surprise scenario employed in the current study relative to the surprise scenario employed in the Olson and Sivak (1986) study.

Second, results clearly indicated that the timing approach employed was subjectively rated by drivers (on average) as "just right" timing under a wide range of combinations of driver speed and lead vehicle decelerations under both expected and unexpected (surprise) lead vehicle braking event conditions. Most importantly, this crash alert timing approach allowed nearly all drivers to respond to the crash alert in a manner which allowed them to avoid impacts during Surprise Moving Trials with the surrogate lead vehicle. During 3.7% of the Surprise Moving Trials conducted (four of 108) across all three interface studies, the passenger-side experimenter intervened to assist the driver in coming to a stop. In 3 of these 4 cases, the driver contacted the brake first. It remains unclear in any of these 4 cases whether these drivers could have avoided impact with the surrogate target (if given the opportunity) without the assistance of the passenger-side experimenter. Overall, these findings provide strong evidence that the deceleration-based crash alert timing approach directly derived/modeled from the CAMP Study 1 findings does an excellent job from a driver performance and preference perspective under both alerted and surprise braking event conditions (i.e., not too early/not too late). These crash alert timing findings are extremely important from a methodological validity standpoint, since *how* to present crash alert information is intimately related to *when* this information is presented. Put in another way, these findings bolster the validity of both the objective and subjective data gathered with respect to the various crash alert types examined, since the crash alert types were presented at an appropriate perceived timing.

Third, it has been argued that a driver following a lead vehicle at a short time headway may be more alert, and hence, have faster brake RTs than a driver following a lead vehicle at a longer (i.e., more conservative) headway (Farber, 1997). These data provide clear evidence against such an assumption, and more generally, against any crash alert timing approach that assumes drivers' brake RTs are related to time headways. Across all studies employing Surprise Moving Trials, the Pearson correlation coefficients (r) between drivers' brake RTs and time headways at lead vehicle braking onset were extremely low. (The corresponding r-values for Study 2, Study 3, and Study 4 were + 0.07, -0.18, and –0.18, respectively.)

Finally, results from a "name the system" questionnaire favored the inclusion of "Forward Collision" as part of the system name (rather than for example, "Rear-End Collision"), in spite of the instruction that the system was not designed for detecting pedestrians (and hence, not everything in the forward scene). However, it should be stressed these naming data are strictly based on driver preferences, and do not provide direct data on what driver expectations (in terms of system performance) would be associated with each of these proposed names. An "open-ended" questionnaire employing naive subjects would provide more direct data for assessing the association between system name and driver expectations.

In summary, the crash alert timing approach developed in CAMP Study 1 (the CAMP required-deceleration based algorithm) received strong validation in these three interface studies. This timing approach appears very promising, and merits future closed-course and in-traffic testing. 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. Prior to these studies, the visual display formats and the auditory alerts were down-sized from numerous alternatives based on questionnaire studies (following ANSI procedures) and laboratory studies, respectively.

Although a multiple-stage alert is allowed under the proposed requirements, a 1-Stage alert is recommended based on the current discovery of a proper "single-point" crash alert timing approach, compatibility with Adaptive Cruise Control system driver alerts being considered, simplicity/elegance from a customer education (mental model) and production implementation perspective, minimizing nuisance alerts, 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).

Based primarily on data from these three interface studies and the previous baseline study (CAMP Study 1), a set of minimum driver interface requirements were developed, which are discussed in Chapter 4.

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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.

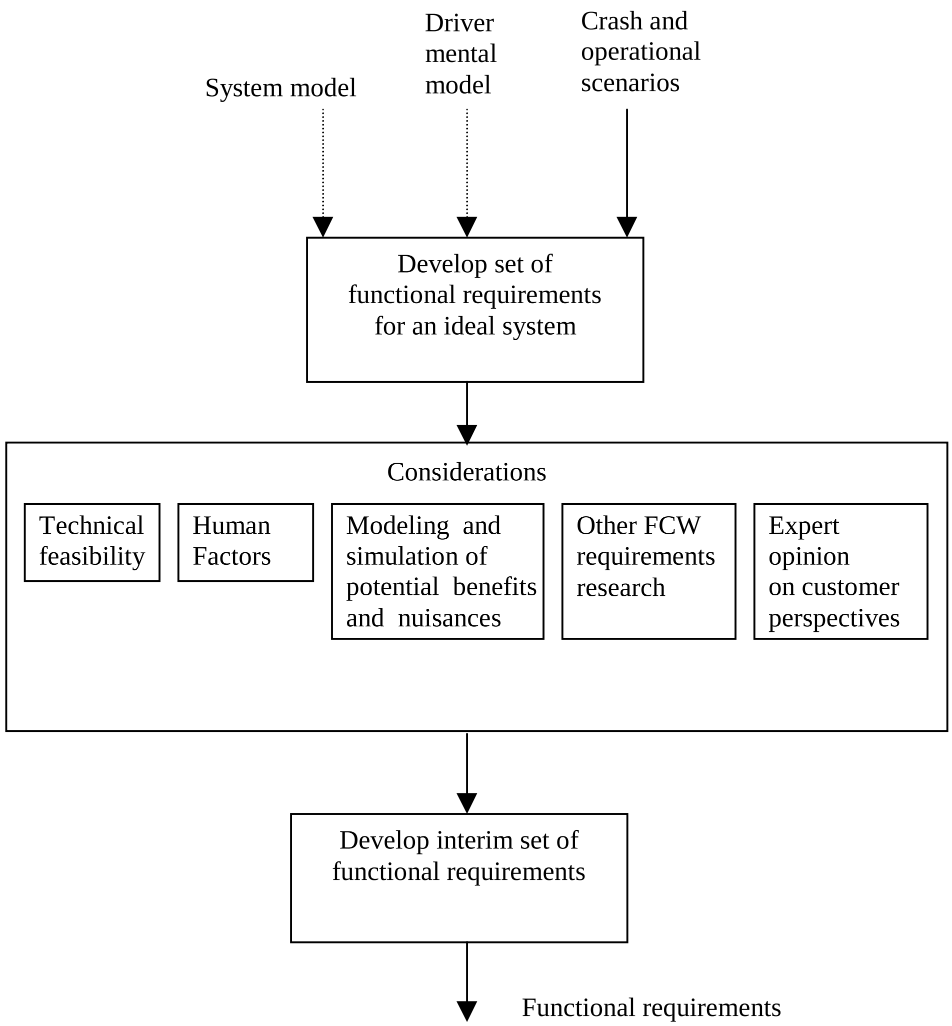


Figure 4-1 FCW System Requirements Development Process

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 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.

Recommended Approach*: *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.

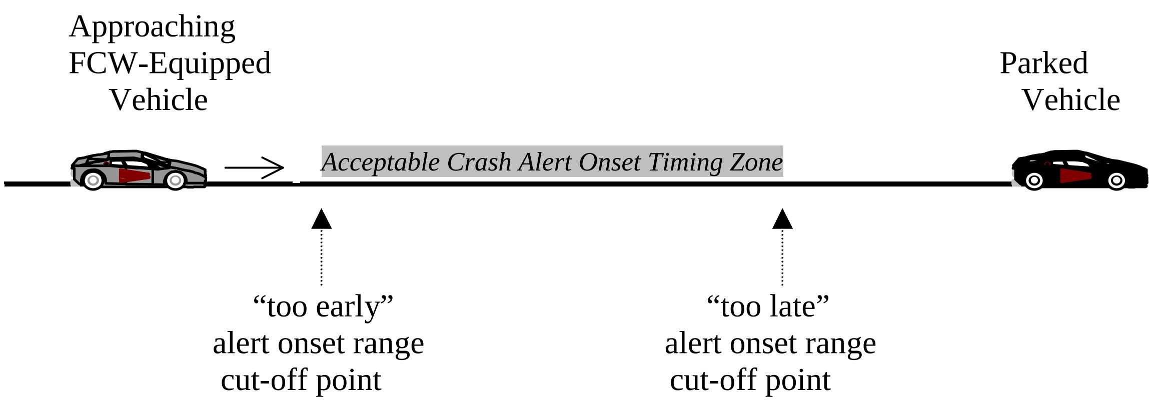


Figure 4-2 Concept of the Acceptable Crash Alert Onset Timing Zone (The case in which the lead vehicle is parked is shown for illustrative purposes.)

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 85th 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 85th percentile actual deceleration values in this context corresponds to accommodating 85 percent of the observed driver braking capabilities, which corresponds to the 15th percentile actual deceleration value shown earlier in Table 3-10.) The relationship between drivers' mean speed in these three speed conditions and these 85th 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 <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. 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.

<u>Recommended Approach:</u> 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.)

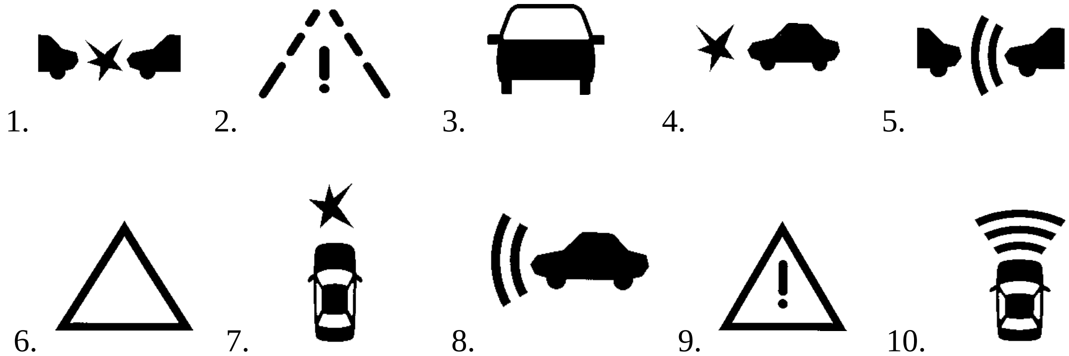


Figure 4-3 Candidate FCW Alert Icons

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.

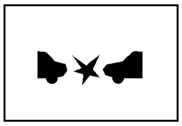
As a result of both the comprehension estimation and open-ended comprehension test procedures administered in accordance with ANSI Z535.3 process, the CAMP visual crash alert icon mentioned above was selected as the top choice of the 10 icons evaluated. It was also found that adding the capitalized word 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.

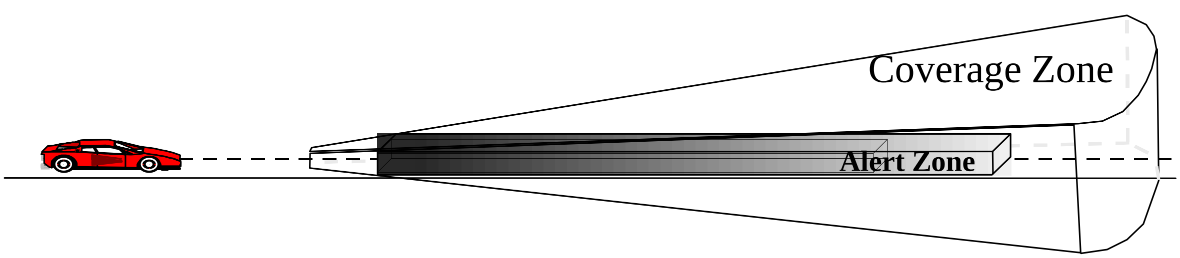


Figure 4-4 Coverage and Alert Zone of a FCW System

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

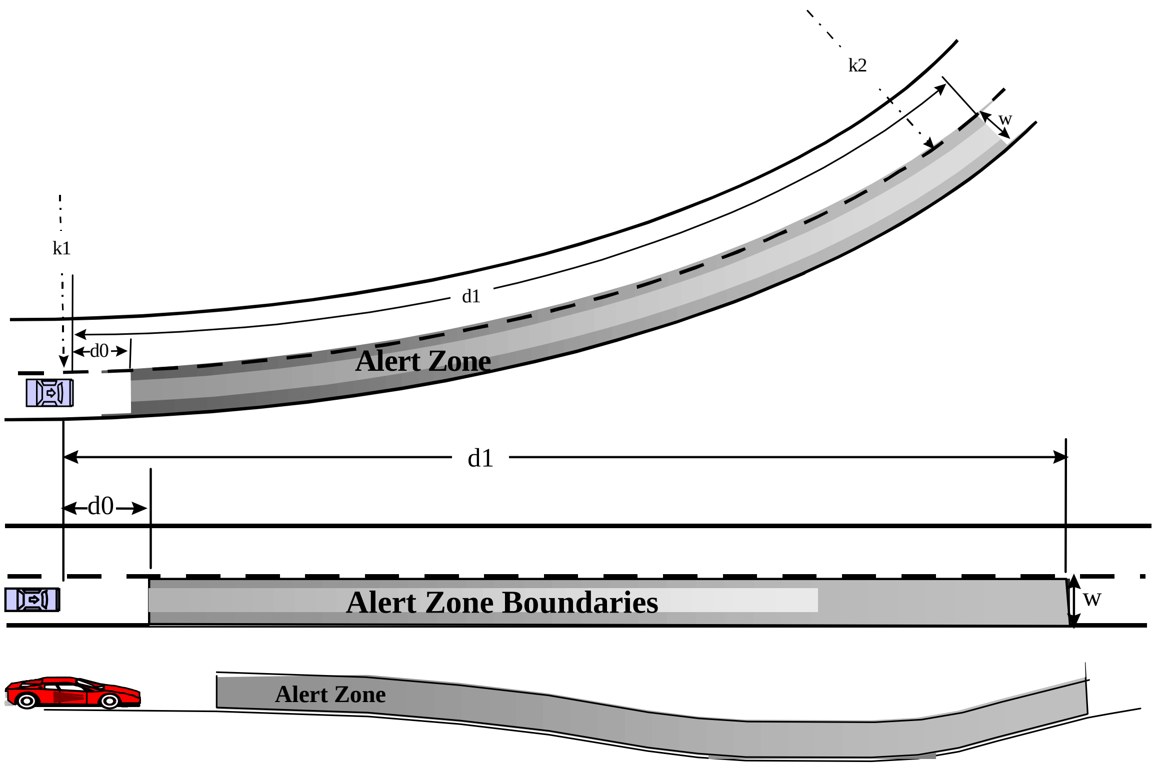


Figure 4-5 Alert Zone Horizontal and Vertical Shape and Size

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.

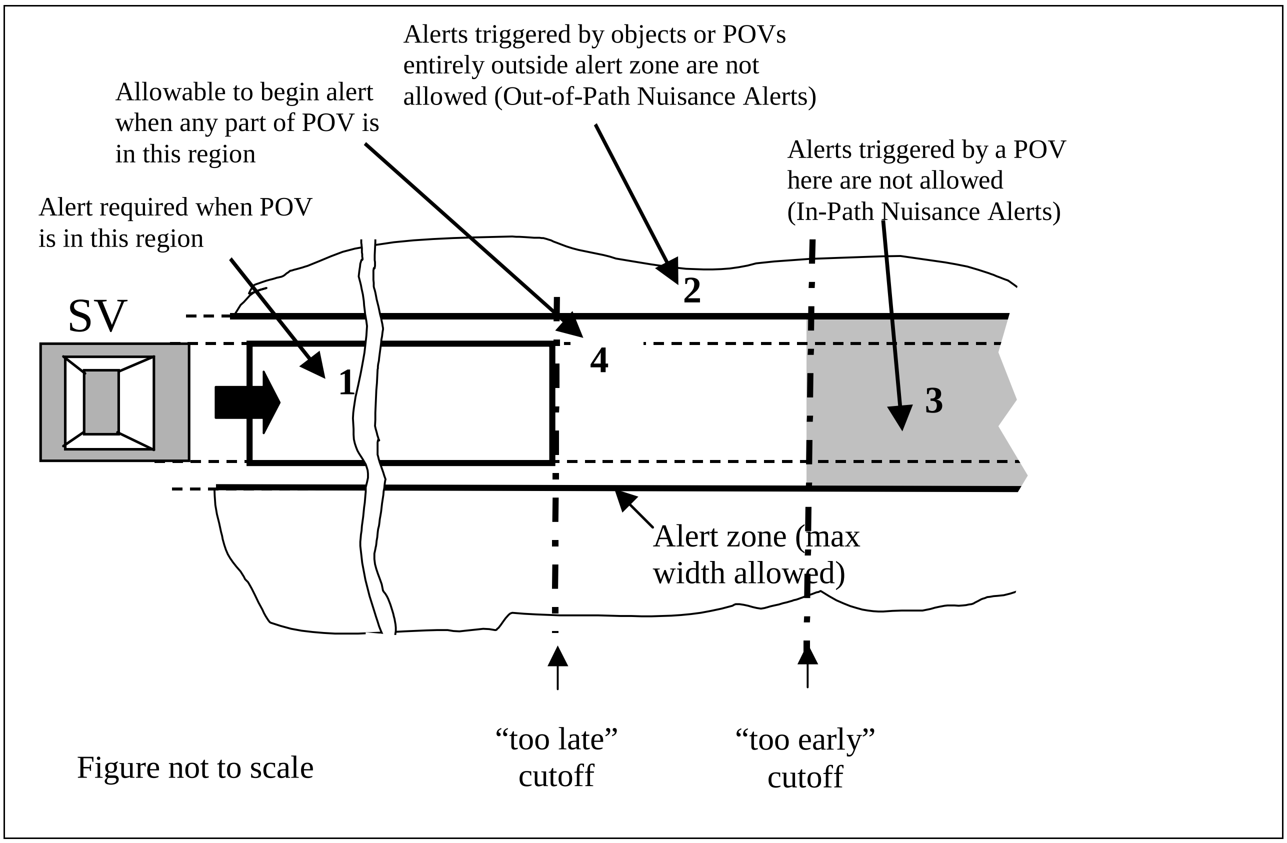


Figure 4-6 POV Locations for Which Crash Alerts are Required, Allowed, and Not Allowed

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.

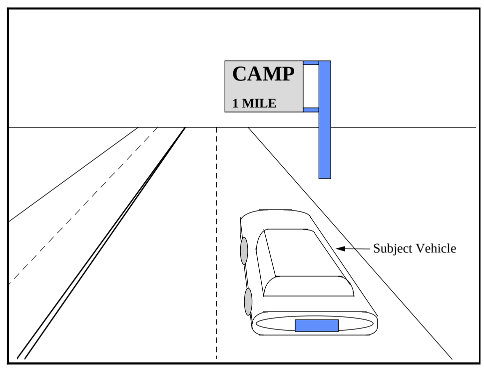


Figure 4-7 Overhead Obstacle

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

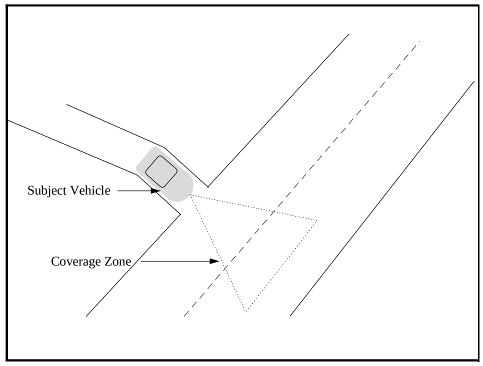


Figure 4-8 Steep Hill

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.

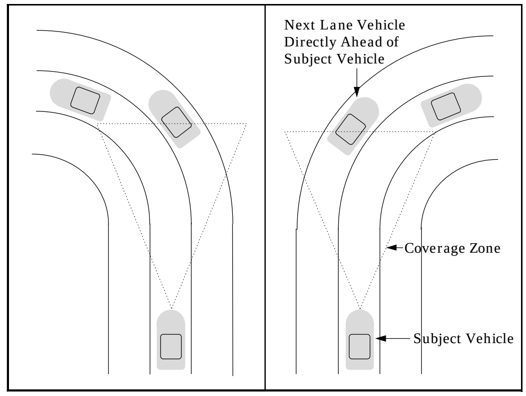


Figure 4-9 Adjacent Lane

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.

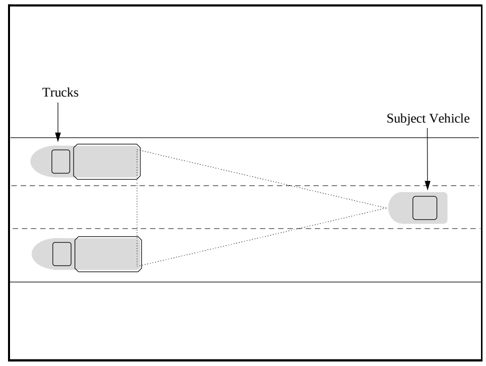


Figure 4-10 Adjacent Vehicles

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

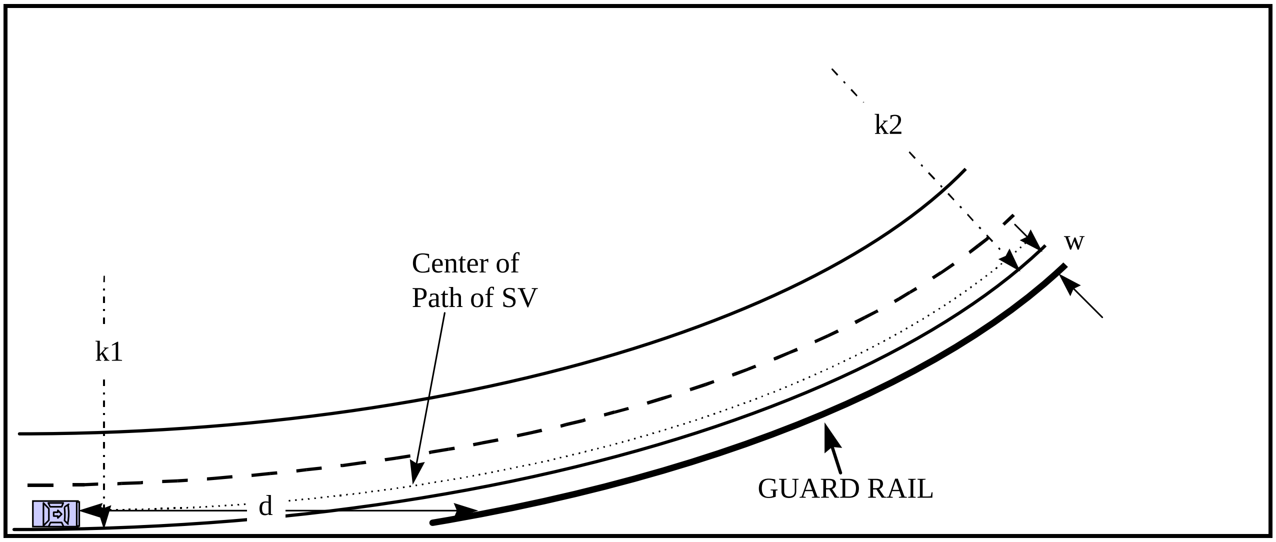


Figure 4-11 Curved Road-Extended Object

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.

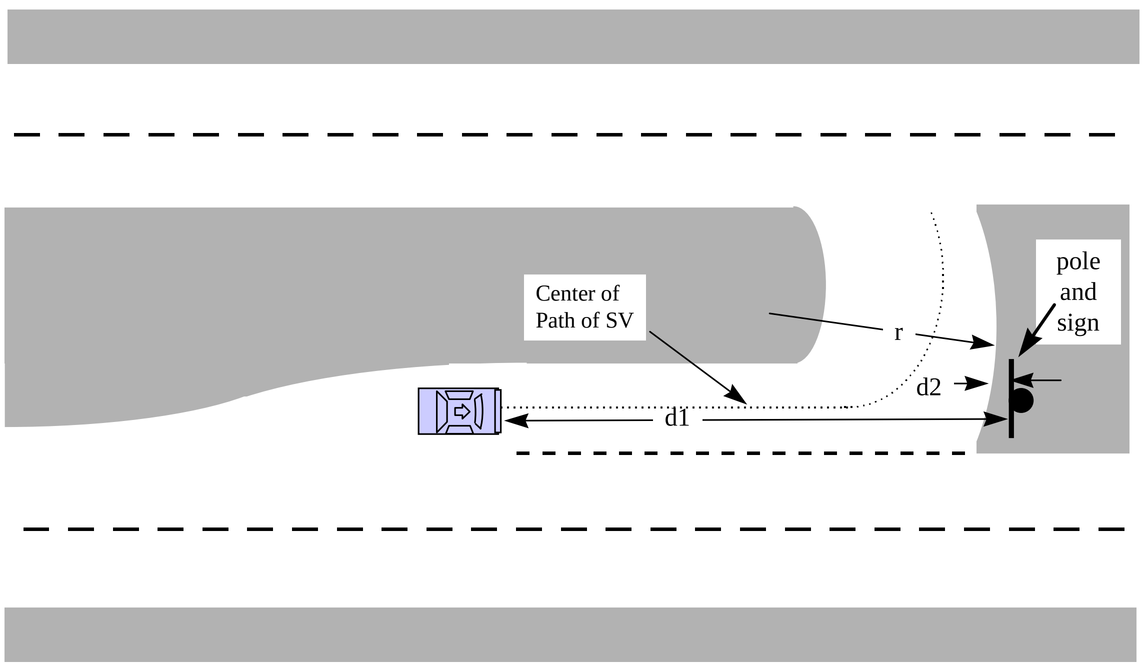


Figure 4-12 Curved Road with Discrete Objects

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.

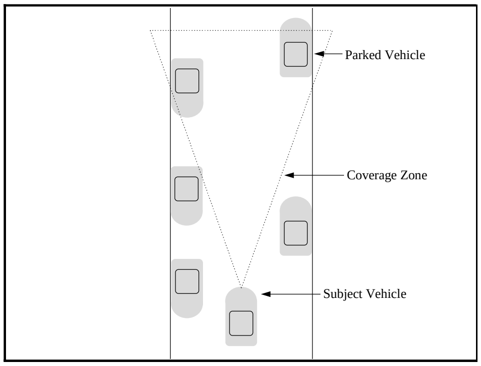


Figure 4-13 Dense Clutter Environment

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.

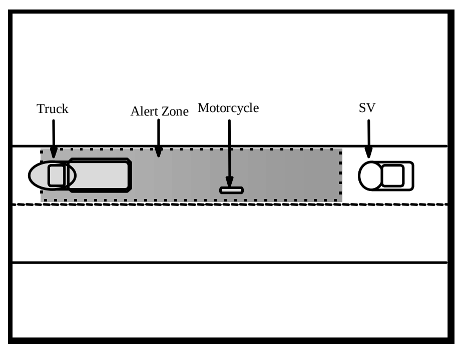


Figure 4-14 Greater Size and Distance

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

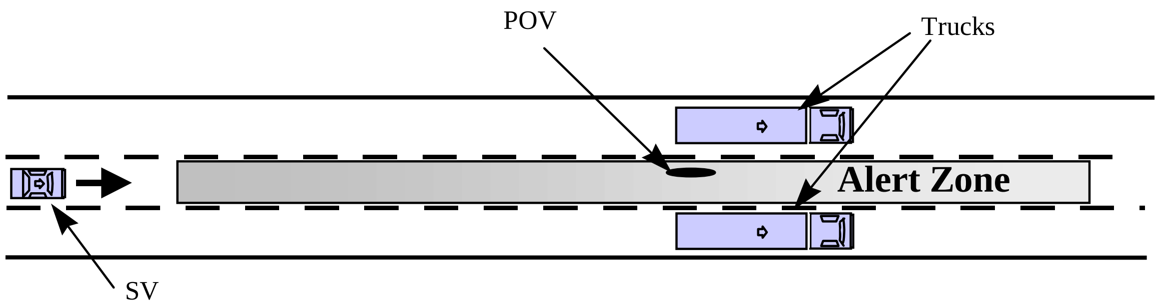


Figure 4-15 Greater Size and Equal Distance

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)

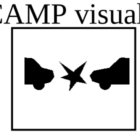
4.7 Requirements Summary

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. <u>*Recommended Approach:*</u> *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°. <u>Recommended Approach</u>: *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

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CHAPTER 5

OBJECTIVE TEST METHODOLOGY FOR FORWARD COLLISION WARNING SYSTEMS

TABLE OF CONTENTS

List of Figures

List of Tables

5 OBJECTIVE TEST METHODOLOGY FOR FORWARD COLLISION WARNING SYSTEMS

5.1 Introduction

This chapter presents an objective test methodology to evaluate the compliance of a Forward Collision Warning (FCW) system with the minimum functional requirements developed in Chapter 4. The core of this methodology is a set of 26 vehicle-level test procedures that evaluate whether crash alerts are issued with acceptable timing in appropriate situations. The tests also evaluate whether crash alerts occur too frequently in situations that drivers are expected to find non-alarming. Because these are minimum requirements for the functionality described in Chapter 1, the countermeasure either passes or fails the testing and no relative rating is provided.

Possible users of the tests are assumed to include vehicle manufacturers, countermeasure suppliers, government organizations, and independent institutions. The tests are designed so they can be executed at a variety of vehicle proving grounds and test track facilities with minimum impact on the test results. To pass testing, a countermeasure must pass each of 17 individual crash alert tests and a set of nine out-of-path nuisance alert tests. The crash alert tests simulate situations in which an alert is required. These tests also evluate the FCW system based on in-path nuisance alerts. The out-of-path nuisance alert tests derive from the operational scenarios and involve simulating common driving conditions in which an alert should not occur, but that may challenge the system being tested. These tests include combining a variety of vehicle speeds, roadway geometries, pavement and lane marking conditions, environmental conditions, out-of-path objects, and more.

The proposed set of tests appear to be practical to execute. The execution time is estimated to be no more than four weeks, based on the experience of executing five of the tests (as reported later, in Chapter 7). The four week estimate does not include initial prop fabrication, set-up, and surveying of test sites. A completely exhaustive set of tests that would evaluate an FCW system in all conceivable circumstances would involve many more tests, and require much longer testing schedules. This is because there are an enormous variety of possible road/vehicle/environment/motion conditions that might affect an FCW system performance. The proposed test set is a best attempt to identify the key FCW performance behaviors in a testing time frame that is practical for government and industry, and is consistent with other safety-related testing regimens.

Regarding driver-vehicle interface requirements of Chapter 4, the objective test procedures presented here address alert onset timing in great depth, but do not address the alert modality. Such tests would follow from established industry practice.

If a countermeasure fails testing, there is a high probability that the system does not meet all the minimum functional requirements. If a countermeasure passes the tests, there is a high confidence that the system would meet the requirements over a wide set of conditions. Nevertheless, field operational testing will be required to learn about drivers' acceptance of the system and its potential effectiveness in the real world.

This chapter covers the test methodology concerned with instrumentation requirements, track and prop requirements, and the test driving maneuvers. An analysis is presented that describes the mapping between requirements and the tests. Chapter 6 covers the data analysis required to evaluate test data, as well as requirements for reporting on the tests. Chapter 7 describes an extensive set of activities undertaken to evaluate and validate the test methodology. This exercise resulted in changes to some important test design parameters and requirements.

The remainder of this chapter is organized as follows. First, an overview of the testing approach and high-level requirements are discussed. Second, definitions used throughout the chapter are presented, along with a set of standard (default) testing conditions. Third, the crash alert testing approach and detailed test procedures are described. Fourth, the out-of-path nuisance alert testing approach and detailed procedures are presented. Fifth, a chart is presented that maps the test procedures back to the functional requirements.

Throughout this report, the term "subject vehicle" (SV) refers to the vehicle on which the FCW is mounted, and "principal other vehicle" (POV) refers to another vehicle in the vicinity.

5.2 Test Methodology Overview

The objective test methodology presented in this chapter includes 26 vehicle level tests in which an FCW-equipped subject vehicle (SV) encounters situations in which a crash alert is either required or is not allowed. Detailed data collection and analysis is required in these tests to determine whether the countermeasure complies with the set of minimum functional requirements developed in Chapter 4.

The test methodology includes several elements that are presented in the remainder of this chapter, as well as in the following chapter. These elements include: test instrumentation requirements; test site and testing props requirements; driving maneuver instructions; and data reporting and analysis requirements. This chapter presents all but the final element, which is given in Chapter 6. The reader will note that beginning with Section 5.3, the methodology is presented as instructions to a party with responsibility for selecting test instrumentation, executing the tests, and analyzing the results to provide the final pass/fail result.

The process used to design the test procedures themselves was described in Chapter 1. Briefly, the functional requirements developed in Chapter 4 are tested in situations derived from the targeted scenarios of Chapter 2. The parameters of the scenarios, such as road geometry, environmental conditions, relative vehicle motions, and roadway scene, are selected from a set of independent variables that attempt to represent the diverseness of driving conditions. The tests are selected to exercise a variety of required FCW system behaviors, and sometimes the parameters of the scenarios are chosen to test important, known technical challenges FCW developers face. The human factors work of Chapter 3 drives the desired timing of the crash alert onset.

The objective test methodology includes two types of tests, which are called “crash alert tests” and “out-of-path nuisance alert tests.” Crash alert tests are situations in which a crash alert must occur with acceptable alert onset timing. Out-of-path nuisance alert tests simulate common driving situations in which alerts are not desirable but may occur due to technical challenges.

The remainder of this section presents important concepts in test methodology approach and design.

5.2.1 Criteria for Passing the Testing

Successful countermeasure performance in testing is defined as passing each of four areas: crash alert tests; out-of-path nuisance alert tests; in-path nuisance alert tests; and driver-vehicle interface tests. Success in each of these areas is defined below. Detailed instructions for computations necessary to determine success in each area are presented in later sections.

5.2.2 Crash Alert Tests

Crash alert test procedures are driving maneuvers involving two or more vehicles. These maneuvers are designed such that the countermeasure-equipped subject vehicle (SV) encounters situations that should trigger a crash alert for a countermeasure system that meets the minimum functional requirements. (See Chapter 4 for these requirements). The significant data from each test trial is a comparison of the time (or position) at which the crash alert onset actually occurred (if they occurred) and the time (or position) at which the alerts were required to occur.

Five trials of each test are performed. Alert onsets should be neither “too late” nor “too early,” as defined in the timing requirements of Chapter 4, Section 2, and the Alert Zone requirements of Chapter 4, Section 3. To pass the testing, a countermeasure must satisfy two criteria. First, in general, the crash alert onset cannot be *too late* for any trial of any test. (Exceptions from this rule are described in Section 5.4.4.) Second, the instances in which the alert onset occurs *too early* are weighted by test, and the weighted sum is compared to a threshold. If the threshold is exceeded, the countermeasure fails testing.

5.2.3 Out-Of-Path Nuisance Alert Tests

Out-of-path nuisance-alert tests determine whether a countermeasure produces too many alerts when confronted with common driving situations. The tests follow closely from the operational scenarios described in Chapter 2. The SV is driven past stationary or moving objects or vehicles that are kept outside the Alert Zone, so that any alert that occurs is an out-of-path nuisance alert. The tests are repeated a specific number of times to represent typical exposures of drivers to common objects, as described later.

The test descriptions include details for the selection and setup of the track and props, driving instructions, and data collection requirements. In general, a system that meets the minimum functional requirements should not produce any alerts during the execution of the tests. If a system does produce alerts during execution of some of the tests, then the specific conditions at the time of the alert are recorded. Again, a weighted sum of instances in which alerts occur are compared to a threshold. The weights and the threshold for out-of-path nuisance alert testing are chosen to estimate the frequency that this type of nuisance alert is likely to occur during typical driving patterns on public roads. If the threshold is exceeded, the countermeasure fails testing.

5.2.4 Driver-Vehicle Interface Tests

The FCW functional specifications in Chapter 4 describe recommendations for the driver-vehicle interface. The requirements for alert onset timing during an approach are tested extensively in the objective test procedures. For the other requirements, however, no specific testing procedures are provided here because the tests for these requirements are considered straightforward and within the realm of current industry practice.

5.2.5 FCW Systems With Multiple Alert Stages and/or Driver-Adjustable Timing

Throughout the remainder of this chapter and Chapter 6, “crash alert” refers to the most urgent level of alert. This is the only alert level for which specific timing requirements are developed in Chapter 4, and the only alert level addressed by the test procedures presented in Chapter 5.

If the FCW system provides any sensitivity adjustment, it should be tuned for testing to the minimum sensitivity to potential threats – that is, to the setting that minimizes the likelihood the unit would issue an alert in a given situation. (This setting might also be called the “latest,” “closest” setting.) Using this setting in testing ensures that a driver who turns down the sensitivity to minimize nuisances will still receive timely alerts in potentially alarming situations. FCW system suppliers may choose to allow the driver to adjust the timing of alerts to accommodate a subset of drivers who may prefer earlier alerts; that is, drivers may be willing to trade-off additional nuisance alerts for the ability to receive earlier alerts.

5.2.6 Independent Variables and Test Procedure Design

Designing a set of test procedures to evaluate a crash countermeasure involves selecting specific examples of key scenarios in which it is desirable to specify and measure countermeasure performance. The driving environment is complex and varied, and drivers are presumed to expect an FCW system to function properly, independent of their driving situation. Therefore, care has been used to ensure that the test procedures explore whether or not a countermeasure will perform with minimum functionality across the vast majority of conditions associated with driving in the U.S., while minimizing the number of tests for feasibility reasons.

Table 5-1 is a list of the independent variables varied over the course of the testing. Also shown are the values taken during at least one test. For example, ambient illumination conditions include daytime and nighttime (which are defined in the Definitions section). Overhead objects include an overhead road sign and an absence of overhead objects. Over 20 independent variables are shown. It is not feasible to test at all combinations. Instead, combinations of variables were selected to test countermeasures in challenging situations considered important for effectiveness and driver acceptance. All values are defined in this chapter.

For example, one test includes the countermeasure-equipped SV approaching a stopped vehicle stopped under a large overhead road sign. This situation is expected to challenge FCW systems that use sensor-processing technologies that lack resolution of targets in the vertical direction. Yet this driving situation is considered common enough and essential enough to successful deployment that the test is included.

Rare combinations of variables that may well confuse FCW systems and are not required for driver acceptance may not be included, in the interests of expediting the deployment of acceptable safety systems that may reduce harm due to crashes.

Table 5-1 Independent Variables that are Varied in the Test Procedures

Independent Variable	Values Required
Environmental Conditions and Visibility	
Ambient illumination	Daytime, nighttime
Atmospheric visibility	Good visibility, fog
POV rear-end retroreflectors	Clean, dusty
Roadway Geometry and Pavement Conditions	
Horizontal curvature	Straight, curved, transition from straight to curved, U-turn
Vertical curvature	Flat road, hill crest, hill sag
Painted lane markings	Good quality, poor quality, none
Road surface wetness	Dry, wet
Road unevenness	Pavement in good shape, poorly paved or unpaved
POVs and Objects in Scene	
Type of POVs	None, mid-sized sedan, motorcycle, truck
Type of object(s) on roadside or in adjacent lanes	None, guardrails, concrete barrier, mailboxes, road signs, slow vehicles
Type of object overhead or on the road surface	None, overhead sign, grating in road, retroreflectors on road, debris on road
Motions of SV and POV	
SV initial speeds	120 kph, 100 kph, 80 kph, 72 kph, 50-70 kph, 30-50 kph, 24 kph.
Initial closing speed (approaching POV)	0 kph, 24 kph, 33 kph, 40 kph, 68 kph, 72 kph, 100 kph
POV deceleration	None, -0.15 g, -0.4 g
Lateral maneuvers before alert	None, POV cut-in, SV lane change

5.2.7 Approach to Instrumentation Requirements

The approach used in the development of these procedures is to allow the testing organizations as much freedom as possible to develop their own approaches to test instrumentation, data processing, and vehicle control. The test procedures levy requirements only on the accuracy with which key *variables* need to be controlled or estimated. No requirements are used to stipulate the use of specific instrumentation, data-processing approaches, and so on.

One motive for this approach is to allow testing organizations the freedom to develop and use innovative approaches to implementing the test procedures. Performing the proposed test procedures will involve staging prescribed vehicle motions and measuring relative motions between vehicles and/or stationary props and/or roads. The testing involves the measurement, estimation, and control of many variables. It seems wise to provide a good testing framework without over-constraining its implementation. A second motive for not specifying highly detailed instrumentation requirements is that instrumentation choices may evolve as technology evolves.

To illustrate the approach, for example, some tests require a vehicle to be driven within a lane such that there is a 95% confidence level that the center of gravity (CG) strays laterally no further than 0.50m from the lane centerline. The user is then responsible to identify hardware and software approaches, and to document the uncertainties associated with the various measurements, and finally to demonstrate in a test report how the requirements given in the test procedures were satisfied. Thus, the testing organizations bear a burden of calibration, analysis, and documentation that would not exist if more specific instrumentation requirements were used.

This approach also has consequences for the recipient of a test report. The recipient of the report will need to examine and assess the validity of arguments in the report regarding measurement uncertainty and the satisfaction of requirements in the test procedures.

Table 5-2 Functions Assigned to Test Procedure Documents, Testing Organization, and Recipients of Test Reports

Test procedures specify the following, including allowable ranges of key variables, where appropriate:	Test conditions allowed (e.g., weather, and illumination). Test set-up, including props (e.g., road geometry, POV descriptions). Directions for executing tests, and required accuracy values for key parameters (e.g., a specified vehicle speed and an allowed deviation from that value). Requirements for the accuracy values of selected intermediate quantities used for countermeasure evaluation (e.g., the accuracy with which the difference in crash alert tests between the range at alert onset and the minimum required distance for an alert must be determined). Countermeasure performance metrics to be computed for each test trial, for use in countermeasure performance evaluation. Instructions for combining the results of individual test runs to determine whether the countermeasure performance meets minimum functional requirements.
The testing organization must select and/or develop the following components of testing:	Instrumentation. Any active control devices used to conduct tests. Calibration procedures. Data processing algorithms for testing purposes. Method of modeling and reporting uncertainties.
Testing organization's responsibilities include:	Identification of measurement, estimation, control, and modeling errors that contribute to uncertainties associated with variables that the test procedures levy requirements upon. Calibration of equipment, when necessary. Describing methods of data processing. Describing how uncertainties are determined. Demonstrating that requirements on test set-up and execution are satisfied, while including the effects of any significant uncertainties associated with instrumentation, control, or data processing. Evaluating appropriate uncertainties associated with test performance metrics.
Recipient of a test report bears these responsibilities:	Assessment of the validity of the testing organization's arguments concerning instrumentation choice and calibration approach. Assessment of the validity of the testing organization's arguments concerning the satisfaction of requirements on accuracy levels associated with test execution and measurement.

5.2.7.1 Handling Measurement Uncertainty Effects

This section describes the scope of the user's responsibility to understand and document effects of measurement uncertainty.

The user is required to show that all accuracy requirements given in this document are met. This may involve reporting calibration procedures as well as presenting work on modeling and analysis. Instructions in this chapter and Chapter 6 should be sufficient to guide the user through this process, but the following examples may provide first-time readers with an understanding of the approach taken in these procedures to dealing with the documentation of calibration and uncertainties.

Example: Roadway horizontal radius of curvature

Roadway horizontal curvature is another independent variable that is specified for each test. The specification is given in terms of a range of allowable radius of curvature values. Users of the test procedures must then report:

- The measured and/or estimated radius of curvature of the test site.
- The means of determining the radius of curvature, and the error in the determination.
- How the error value was found.

An argument for a 95% confidence level that the test site radius of curvature satisfies the requirement.

The recipient of the report might choose to examine the claims and justifications related to the actual measured value of the radius of curvature, as well as the argument that the measurement translates into an acceptable radius of curvature value (with 95% confidence).

Example: Computation of Crash Alert Performance Metric

For crash alert tests, the metric of countermeasure performance is the difference between the range at alert onset and the minimum required range at alert onset (which depends on the relative speed between the vehicles). The test procedures require that this metric be computed with an accuracy (95% confidence) equal to either 5% of the minimum required warning range, or 2.0 m, whichever is larger for the situation. Users of the test procedure must then report:

- The means of estimating the metric for each trial, including sensor descriptions, data-processing techniques and algorithms.

- A model of the estimation error associated with the computed metric and a justification for the model.
- Any calibration procedures used to arrive at the estimation error model.
- Any modeling and analysis that supports the algorithm development or the specification of the associated estimation error.

5.2.7.2 Instrumentation Non-interference

The instrumentation necessary for this test must be installed such that it does not hinder operation of the subject vehicle or countermeasure, or the operating characteristics of either.

5.3 Definitions and Standard Testing Conditions

This section presents detailed definitions of some technical terms used in the chapter. First, definitions are presented for some of the independent variables, which are quantities used to describe testing conditions. Second, additional definitions are given to aid the reader. Throughout this report, the term "subject vehicle" (SV) refers to the vehicle on which the FCW is mounted, and "principal other vehicle" (POV) refers to another vehicle in the vicinity.

5.3.1 Definitions of some Independent Variables

Part of the description of each test is the set of values taken on by a set of independent variables, which are listed in this section, along with definitions used to refer to particular conditions.

For example, a "straight road" is defined as a road with a horizontal curvature of less than 0.1 deg/100m. Some conditions cannot be described so simply. For example, used to represent roadside objects, such as a speed limit sign, require a more lengthy description.

5.3.1.1 Environmental Conditions

"Daytime illumination" is defined as the natural outdoors illumination that occurs from 30 minutes after sunrise to 30 minutes before sunset.

"Nighttime illumination" is defined as the natural outdoors illumination available from the time beginning one hour after sunset and ending one hour before dawn.

"Good atmospheric visibility conditions" are defined as greater than 1-kilometer visibility using the Runway Visibility Rating (RVR) or similar methods.

"Poor atmospheric visibility" conditions are defined as less than 200-m visibility using the Runway Visibility Rating (RVR) or similar methods.

"Very windy conditions" exist if either sustained wind speeds exceed 30 kph or wind gusts exceed 40 kph.

5.3.1.2 Objects in the Scene

"Passenger car" is defined arbitrarily as a 1997 Chevrolet Lumina LTZ, or another similarly sized mid-sized sedan.

"Large truck" is one similar to the 24-foot bed enclosed moving trucks commonly available from rental agencies. An example is a 1995 Ford F-700.

“Motorcycle” is defined as a commercially available 350cc to 650cc-class motorcycle without alterations to its reflectors, lights, or fenders, and without after-market add-ons that might affect its visibility to countermeasure sensors.

5.3.1.3 Roadway Description

“Straight road” is tentatively set at a horizontal curvature of less than 0.1°/100m.

“Flat road” is set at a vertical curvature of greater than 600-m% change in grade.

“Smooth pavement” conditions describe any paved track surface with pavement in relatively good condition.

“Unpaved” conditions describe any surface that is not paved.

Painted Lane Markings

“Painted lane markings” refers to markings that are painted on the road surface or that consist of material laid down onto the surface such that the markings appear similar to painted markings. Three types are defined here: *no lane markings, poor quality painted lane markings,* and *good quality painted lane markings.* The test procedures for each test will require that the roadway have one of these particular types of lane markings. In general, test sites should have lane markings that are consistent with standard marking patterns.

The center of any marked lane must be parallel to the center of the road. Lane widths and variations should comply with AASHTO standards for highways and streets (AASHTO, 1995).

Note that these definitions are not intended to provide any sort of classification of actual public roadways, or to provide a comprehensive description of situations that do or do not challenge countermeasures that may sense lane markers.

No Lane Markings

For tests to be executed on roadways with "no lane markings," the roadway should have no painted lane markings and no raised pavement markings (e.g., retroreflectors indicating lane edges). The roadway should be no more than 7.4 m wide (equal to the width of two 12-foot lanes). The roadway width should also be approximately constant and surrounded by surfaces different enough from the roadway so that a driver can easily distinguish the road from the surrounding space. Therefore, for example, these tests cannot be executed on the wide expanses of pavement commonly used at automotive proving grounds for vehicle dynamics testing (sometimes called "black lakes").

Good Quality Painted Lane Markings

A test to be executed on a roadway with "*good quality*" painted lane markings must be executed on a roadway where all of the following conditions apply to the travel lane:

- The painted lane markings must be either single solid (continuous) lines or single dashed lines. Neither side of any lane used in the test can be marked with double-solid lines nor a combination of parallel solid and dashed lines, such as the markings found on a two-way, two-lane road, with no passing in one direction.
- The painted lane markings must be either yellow or white.
- Raised pavement markers are acceptable but not required.
- The painted lane markings must be between 3.5 and 5.5 inches wide.
- If a painted lane marker is dashed, the following must hold:
    - The length of all dashes must be between two and 10 meters.
    - The space between two dashes cannot be less than *twice* the length of either dash or greater than *four* times the length of either dash, where the length of each dash is its "ideal" length, which is not reduced by wear or torn off sections of marker.
- The integrity of the painted surfaces must be as follows: Let the area of an ideal painted marker be the area of a continuous strip with a width equal to the average width of the lane marker. For a solid line the area of paint or material that makes up the actual lane marker is then required to be at least 25% of the area of the ideal continuous strip. This should be true over any 20 m length of lane marking. For a dashed line, the area of actual paint should be at least 10% of an ideal continuous stripe. (Note that if the spaces between dashes are

four times the length of the dash, and each dash is missing half its original painted surface, the area of actual paint is 10% of an ideal continuous stripe.)

These requirements are based on engineering judgment. A computer vision image processing system that identifies lane markings typically use both intensity contrast between pavement and lane markings, as well as the continuity of the marker in each image and in an image sequence. Therefore, the difference in the percentage area requirements for solid and dashed lines, reflects an educated opinion; that systems in the near-term will have less difficulty identifying the appropriate contrast threshold for a solid line than for a dashed line, because the continuity of a solid line aids the process.

Poor Quality Painted Lane Markings

For tests to be executed with "poor quality painted lane markings," the roadway must meet all the conditions for good quality painted lane markings, except:

- No raised pavement markers are allowed.
- The integrity of the painted surfaces must be as follows: For solid lines, the area of the actual remaining marker should be between 5% and 25% of an ideal continuous stripe. For dashed lines, the area should be between 3% and 10% of an ideal continuous stripe. These values are again based on engineering judgment.

5.3.1.4 Vehicle Motions

"Vehicle speed" is identical to "Longitudinal velocity" in SAE J670e, "Vehicle dynamics terminology," (Last revision July 1976).

"Vehicle acceleration" refers to "Longitudinal acceleration" in the same reference.

"Range" is the distance from the front of the FCW-equipped vehicle to the rear of another vehicle.

5.3.2 Other Definitions

"Alert zone" is defined in Chapter 4, Section 4.3.

"Testing distance" for the out-of-path nuisance alert tests is defined when stationary objects are used. The testing distance begins when the SV is 200 m from the stationary object(s), and ends when the SV has passed the last stationary object used in the test.

5.3.3 Standard Testing Conditions

Unless specified otherwise, all tests should be run under the following conditions:

5.3.3.1 Standard Roadway Geometry and Conditions

For individual test trials, both the roadway geometry parameters and the roadway conditions must meet the specifications given in the testing procedures. Unless specified otherwise, the road surface should be dry (without visible moisture on the surface). Unless a particular test specifies otherwise, the roadway should be straight, flat, with pavement in good condition (where these properties are described in the Definitions section). The surface itself should be constructed from asphalt or concrete. The road surface should be free from potholes, bumps, and cracks that could cause the SV to pitch excessively.

Painted lane markings of "good quality" – as defined in the Definitions section – should exist on the roadway.

5.3.3.2 Standard Environmental Conditions

Unless a particular test specifies otherwise, the tests should be ran during daylight hours, with good visibility. There should not be very windy conditions, and the ambient temperature should be between –18 deg C (0 deg F) and 38 deg C (100 deg F). See the Definitions section for specific definitions of these conditions.

5.4 Crash Alert Test General Requirements

This section addresses issues common to a wide array of the crash alert tests. The first major subsection defines standard testing conditions that are to be used in the crash alert tests, unless otherwise specified later, under the description of the individual tests in the section Crash Alert Tests. For example, this section defines the default value for required ambient illumination as "Daytime illumination." Later, in the detailed test procedures, a few crash alert tests stipulate "Night-time illumination."

The second major subsection below addresses requirements for test instrumentation. The variables to be measured or estimated for most crash alert tests are listed; special needs for specific tests are given later in the Section 5.2.2. The level of specificity of the instrumentation requirements is consistent with the discussion in Section 5.2.6.

5.4.1 Track and Prop Preparation

5.4.1.1 Principal Other Vehicles

The test procedures specify the type(s) of principal other vehicles (POVs) to be used for each test. There are three types: Mid-size sedan, Motorcycle, and Truck. Readers should consult the Definitions for specific definitions of the POV types. Unless the POV type for a particular crash alert test is otherwise specified, the default value for the POV type in crash tests is Mid-size sedan.

Unless a specific crash alert test specifies otherwise, the POVs should be clean and without alterations that might affect the ability of a countermeasure to sense and track the vehicle.

5.4.1.2 Instructions for Preparing a Stopped-POV Test

Several crash alert tests involve a stationary POV. To prepare for these tests, park the POV in the center of a travel lane, with its longitudinal axis oriented parallel to the roadway edge, and the POV facing the same direction as the front of the SV, so the SV approaches the rear of the POV. The configuration should satisfy the following:

- The CG of the POV must be no more than 0.30-m, from the center of the lane of travel.

- The angle between the POV's geometric longitudinal axis and the local road edge cannot exceed 2.5 degrees.

5.4.1.3 Other Objects in the Scene

Unless stated otherwise, all crash alert tests should be conducted such that there are no overhead signs, bridges, or other significant structures over, or near, the track for the duration of the test. (Test duration is defined in the detailed procedures of each test). The track setup and the test execution should also ensure that roadside clutter effects are negligible. For instance, the SV should not be driven on the outside lane of a track with guardrails located quite close to the lane, since guardrails are potential sources of out-of-path nuisance alerts, and those alerts are addressed in a different test set.

5.4.2 Instrumentation Requirements

5.4.2.1 Instrumentation Requirements for Test Validity Analysis

Instrumentation should support the determination that independent variables meet requirements (e.g., that the roadway satisfies the "flat road" specification). Instrumentation must also support the determination that the tolerances specified in the driving instructions for a particular test are satisfied during the execution of each test trial.

Any additional instrumentation requirements needed for a particular crash alert test are stated within the procedures for each test.

Additional instrumentation requirements to characterize countermeasure performance are described in the next section. Data rates are not specified: the user of these procedures selects the data rates.

5.4.2.2 Instrumentation Requirements For Determining Countermeasure Performance

Instrumentation for crash alert tests must support the determination of whether the crash alert occurs, and if so, whether the alert occurs for appropriate targets with appropriate timing. Each crash alert onset must occur at a range which is no less than the minimum allowable range at alert onset and still no greater than the maximum allowed range at alert onset (from considerations of in-path nuisance alerts, as discussed in Chapter 4).

The minimum and maximum allowed range at alert onset are discussed in Chapter 4, Section 2. Appendix B presents detailed instructions to compute these alert timing requirements, given measurements of vehicle speeds and accelerations.

Knowledge of the relative lateral position is used to determine whether the POV was within the Alert Zone at any instant of interest. The accuracy requirements for locating the lateral position of the POV relative to the SV, in road coordinates, near the time when an alert is expected, is suggested to be 0.2m (with 95% confidence).

Consider now accuracy requirements associated with determining whether an alert occurs at a range that satisfies the minimum functional requirements in Chapter 4. Let R denote the range from the SV to the POV at the time of an alert onset. Let $R_{warn,\min}$ denote the minimum range at which alert onset is allowed, under the prevailing kinematic conditions. (See Chapter 4 for the minimum required warning range and the maximum allowed warning range, expressed as a function of SV and POV speeds and accelerations.) Let ε_R be the difference between the range at alert onset and the minimum required alert range at that moment, $\varepsilon_R = R - R_{warn,\min}$. This is illustrated in the figure below. This difference ε_R is an essential metric used to evaluate countermeasure performance. Requirements are now levied on the accuracy with which this metric should be computed:

- The 3-sigma uncertainty in ε_R, the difference between the range at which the required crash alert occurs, and the minimum range for the required crash alert cannot exceed 5% of the minimum warning range or 2.0 m, whichever is greater.

These requirements will drive the accuracy needs associated with computing range, range rate, and the vehicle accelerations. Accuracy needs for other quantities, such as the vehicle speeds and the knowledge of the timing of the alert onset, may be driven by the above requirements.

Likewise, let $R_{warn,\max}$ be the maximum allowed range for the onset of an alert, given the instantaneous range, range rate, and relative longitudinal acceleration. Let ε_{IPNA} be the difference between the range at alert onset and the minimum required alert range at that moment, $\varepsilon_{IPNA} = R - R_{warm,\max}$. (The subscript "IPNA" stands for in-path nuisance alert.) Consider the following accuracy requirement:

- The 3-sigma uncertainty in ε_{IPNA}, the difference between the range at which the crash alert occurs and the maximum allowed range for the crash alert onset, cannot exceed 5% of the maximum allowed warning range, or 2.0 m, whichever is greater.

5.4.3 Data Analysis and Reporting

Data reported must demonstrate "test validity," that is, that the test run meets specifications given for each test in the Driving instructions. Reporting of these variables is required.

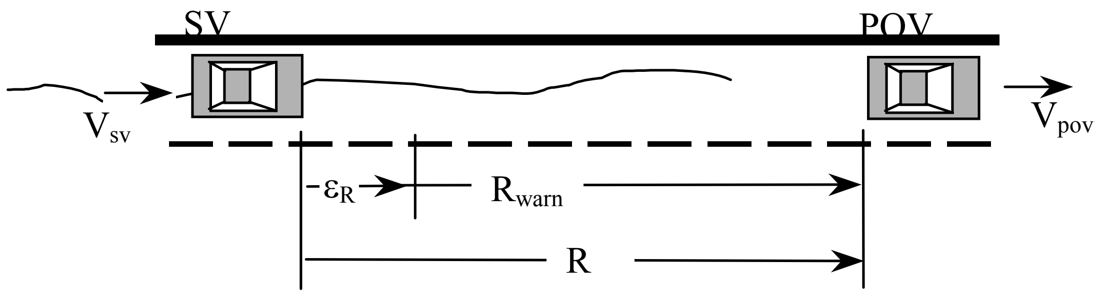

Figure 5-1 **Metric for Countermeasure Performance for Crash Alert Tests**

Data analysis must also evaluate and document the performance of the countermeasure for the required crash alerts. For test scenarios without significant lateral maneuvers, these four quantities generally suffice, unless stated otherwise in the Chapter 6:

- The performance metric ε_R, which is the difference between the range at which the alert occurs and the minimum range for the alert onset.
- The uncertainty associated with the metric ε_R.
- The performance metric ε_{IPNA}, which is the difference between the range at which the alert occurs and the maximum allowed range for the alert onset.
- The uncertainty associated with the metric ε_{IPNA}.

Individual tests may have special instructions in addition to these variables. See Chapter 6 for detailed instructions on all data reporting and analysis requirements.

5.4.4 Crash Alert Test Repetition Requirements

Each crash alert test must be executed five times, and possibly more, depending on the results of the five trials. For each test, the countermeasure must issue the alert "soon enough" for each trial. (Requirements for alert onset timing are described in Chapter 4; an algorithm to compute requirement values for specific speeds and accelerations is given in Appendix B.) Should the system be "late" on one trial, 15 additional trials are required with no allowed instances of being too late before the system can pass the testing. Fifteen trials are required to show that the "late" performance is a rare event (due, perhaps, to test instrumentation inaccuracies). If the system passes the additional trials, there is no need for an explanation or analysis of the single "late" trial.

The countermeasure should not issue alert onsets "too early," either. A weighted sum of the instances in which alert onsets occur too early is compared to a threshold, as described in Chapter 6. If more than five trials are required for any test, the weighting method described in Chapter 6 allows the additional trials to be included in the weighted sum in a manner that does not penalize the need for extra trials.

5.5 Crash Alert Tests

Crash alert tests investigate the countermeasure's compliance with functional requirements that address the timing of crash alert onset timing and poor visibility functions. The list of crash alert tests is given below.

Test	Test name
C-1	100 kph to POV stopped in travel lane (night)
C-2	80 kph to POV at 16 kph (uneven surface)
C-3	100 kph to POV braking moderately hard from 100 kph
C-4	100 kph to POV stopped under overhead sign
C-5	100 kph to slowed or stopped motorcycle
C-6	SV to POV stopped in transition to curve (wet pavement)
C-7	SV to POV stopped in a curve without lane markings
C-8	SV to slower moving POV, in tight curve
C-9	POV at 67 kph cuts in front of 100 kph SV
C-10	SV at 72 kph changes lanes and encounters stopped POV
C-11	100 kph to stopped POV, with fog.
C-12	POV brakes while SV tailgates at 100 kph.
C-13	Greater size and equal distance (100 kph SV approaches 32 kph motorcycle that is alongside two 32 kph trucks)
C-14	Greater size and greater distance (100 kph SV approaches 32 kph motorcycle that is behind a 32 kph truck)
C-15	100 kph to 32 kph truck
C-16	SV to POV stopped in transition to curve (poor lane markings)
C-17	24kph SV to stopped POV.

Table 5-3 List of Crash Alert Tests

Test requirements and procedures are now given for each of these tests.

5.5.1 Test C-1 100 kph to POV Stopped in Travel Lane (Night)

5.5.1.1 Test Overview and Purpose

This test consists of a SV traveling on a straight, flat road at highway speed toward a vehicle which is parked in the middle of the lane of travel. The test should be performed at night. The test is to determine whether the countermeasure crash alert onset occurs at a range that is consistent with the alert onset timing requirements described in Chapter 4, Section 2. The test is also used to estimate the expected exposure to in-path nuisance alerts for the countermeasure. The test assures that the countermeasure functions appropriately at the maximum speed and sensing ranges described in Chapter 4. The test also ensures that the FCW functions appropriately even with nighttime lighting. .

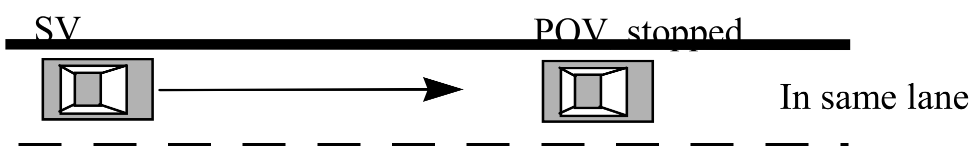

Figure 5-2 Test Maneuver Diagram for Test C-1

This test addresses Chapter 2 crash scenarios that include the following: Distracted driver rear-end (RE), Inattentive driver RE, and Aggressive driver RE.

5.5.1.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Description

POV type: Midsize sedan

5.5.1.3 Environmental Conditions

Use standard conditions, per Section 5.3.3.2, except run this test with nighttime illumination and no direct lighting (e.g., no “streetlights” are permitted).

5.5.1.4 *Instrumentation Requirements*

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

Additional instrumentation requirements for this test include:

- The location and orientation of the stopped POV should be as stipulated in the general crash alert requirements.

5.5.1.5 *Driving Instructions*

The POV should be parked in the lane of travel, as described in Crash Alert Tests General Requirements. The position of the stationary POV should be determined, if necessary. (Only the relative position of the SV with respect to the POV is needed, and some measurement approaches will make absolute knowledge of the POV position unnecessary.)

Drive the SV at a nominal speed of 27.8 m/sec (100 kph) in the center of the lane of travel, toward the parked POV. The test begins when the SV is 200m from the POV and ends when either of the following occurs:

- The required crash alert occurs.
- The range to the POV falls to less than 90% of the minimum allowable range for the onset of the required crash alert.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

For the nominal SV speed, the maximum allowed alert onset range is 146.1m and the minimum allowed range for alert onset for the crash alert is 100.0m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than two kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal

to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).

- The SV driver cannot touch the brake pedal before the required crash alert occurs, or before the range falls to less than 90% of the minimum range allowed for onset of the required crash alert.

5.5.2 Test C-2 80 kph to POV at 16 kph on uneven road

5.5.2.1 *Test Overview and Purpose*

This test consists of a SV traveling on a straight, flat road toward a single POV, which is moving in the same lane at a much slower speed. The test is performed on a road that is either unpaved or poorly paved. The test is to determine whether the countermeasure crash alert occurs at a range that is consistent with the alert onset timing requirements of Chapter 4. The test is also used to estimate the expected exposure to in-path nuisance alerts for the countermeasure. The test also ensures that the FCW can operate on pavements that will induce pitching motions of the SV.

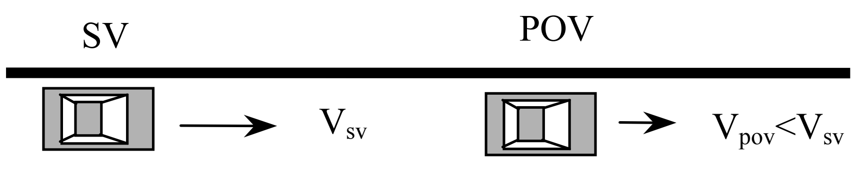

Figure 5-3 Test Maneuver Diagram for Test C-2

This test addresses Chapter 2 crash scenarios that include the following: Distracted driver RE, Inattentive driver RE, and Aggressive driver RE.

5.5.2.2 *Track and Prop Setup*

Roadway Geometry Conditions

Use standard conditions, per Section 5.3.3, except that an unpaved or poorly-paved road segment should be used. The purpose of this is to induce vehicle vibrations that may pose a challenge to some countermeasures. The term “poorly paved” is intended to suggest a public road in poor repair. This test is not intended to be executed on extremely uneven pavement situations, such as those available at many proving ground facilities for chassis testing.

POV Description

POV type: Midsize sedan

5.5.2.3 Environmental Conditions

Use standard conditions, per Section 5.3.3.2.

5.5.2.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

5.5.2.5 Driving Instructions

Throughout the test, the POV is to be driven at a constant 22.2 m/sec (80 kph) in the center of the lane of travel.

The SV is to be driven at 4.4 m/sec (16 kph) in the center of the lane of travel, toward the slower-moving POV. The test begins when the SV is 150m from the POV and ends when either of the following conditions is satisfied:

- The required crash alert has occurred.
- The range to the POV falls to less than 90% of the minimum allowable range at alert onset for the required crash alert.

After one of these events occurs, the SV driver is to steer and/or brake to keep the SV from striking the POV.

For the nominal SV speed, the maximum allowed alert onset range is 97.6 m and the minimum allowed range for alert onset for the crash alert is 62.9m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold from the beginning until the end of the test:

- The POV vehicle speed cannot deviate from the nominal speed by more than two kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The SV vehicle speed cannot deviate from the nominal speed by more than two kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The CG of the POV cannot deviate more than 0.30m away from a line parallel with the lane centerline (with a confidence level of 95%).

- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).
- The SV driver cannot touch the brake pedal before the required crash alert occurs, or before the range falls to less than 90% of the minimum range allowed for onset of the required crash alert.

5.5.3 Test C-3 100 kph to POV Braking Moderately Hard from 100 kph

5.5.3.1 Test Overview and Purpose

This test begins with the SV traveling on a straight, flat road at highway speed. Ahead of the SV, in the same lane, is a single POV, which is initially traveling at the same speed as the SV. The SV is following at a moderate distance. The POV then begins to brake moderately hard, so that the SV begins closing on the POV. The SV maintains a constant speed until the required crash alert is triggered or the range decreases to less than the minimum allowed range for alert onset.

The test determines whether the countermeasure's required crash alert occurs at a range that is consistent with the alert onset timing requirements of Chapter 4. This test especially explores the ability of the countermeasure to issue timely warnings with a decelerating lead vehicle (see also Test C-12.) The test is also used to collect data for use in estimating expected exposure to in-path nuisance alerts for the countermeasure.

This test addresses Chapter 2 crash scenarios that include the following: Distracted driver RE; Inattentive driver RE; Aggressive driver RE.

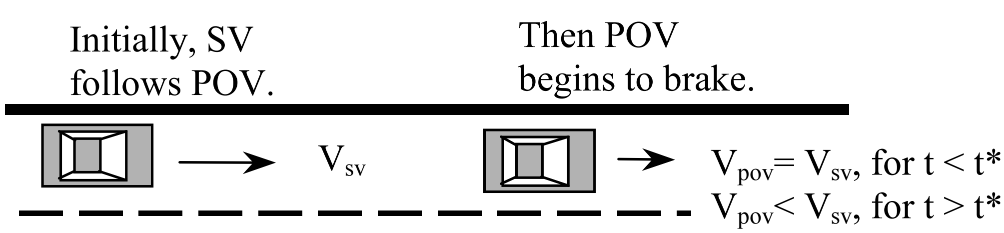

Figure 5-4 Test Maneuver Diagram for Test C-3

5.5.3.2 Track and Prop Setup

Roadway Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Description

POV type: Midsize sedan.

For this test, the rear of the POV (and especially the brake lamps and retroreflective surfaces) should be dusty. This may challenge some countermeasure sensing systems.

5.5.3.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.3.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

5.5.3.5 Driving Instructions

To begin the test, the SV and the POV are each to be driven at a constant 27.8 m/sec (100 kph) in the center of the lane of travel. The headway from the SV to the POV should be 2.0 seconds. The POV then begins a braking maneuver of moderate intensity; the deceleration profile is described below. During the test, both vehicles should remain near the center of the lane. Allowable tolerances are given below.

The test begins seven seconds before the POV begins the braking maneuver, and ends when either of the following conditions is satisfied:

- The required crash alert has occurred.
- The range to the POV falls to less than 90% of the minimum allowable range at alert onset for the required crash alert.

After one of these events occurs, the SV driver is to steer and/or brake to keep the SV from striking the POV.

For the nominal initial speeds and assuming an *ideal* POV braking profile – a step change from constant speed to –0.32g – the maximum allowable range for onset of the crash alert would be 54.1 m and the minimum allowed range at alert onset would be 49.5 m.

(Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must be satisfied:

- The initial POV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The difference between the initial SV and POV speeds cannot be larger than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The range between the SV and POV, during the seven seconds before the POV begins to brake, must be equivalent to a headway of 1.85 to 2.15 seconds, based on the SV speed.
- The CG of the POV cannot deviate more than 0.30m away from a line parallel with the lane centerline during the entire test.
- The braking profile of the POV must satisfy the following:
    - 1.5 sec after the braking maneuver begins, the deceleration should nominally be -0.32g, with an acceptable error magnitude of 0.03g, until the test is over (see above for definition of the end of the test).
- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).
- The SV driver cannot touch the brake pedal before the required crash alert occurs, or before the range falls to less than 90% of the minimum allowable range for onset of the required crash alert.

5.5.4 Test C-4 100 kph to POV Stopped Under Overhead Sign

5.5.4.1 Test Overview and Purpose

This test consists of a SV traveling on a straight, flat road at highway speed toward a POV which is parked under an overhead sign, in the middle of the lane of travel. The test explores the countermeasure's ability to distinguish threats in the roadway from non-threatening objects over the roadway. The test is also used to collect data for use in estimating expected exposure to in-path nuisance alerts for the countermeasure.

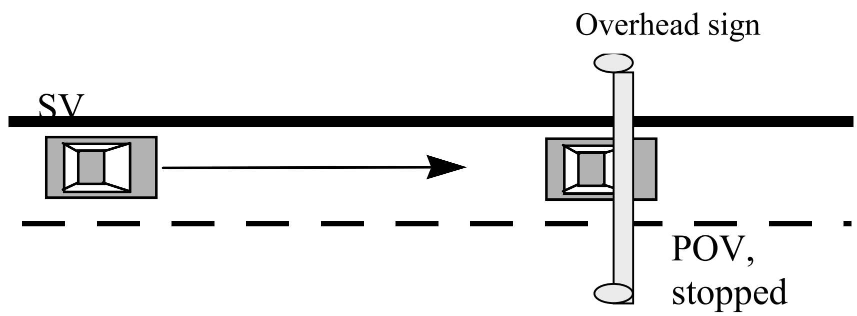

Figure 5-5 Test Maneuver Diagram for Test C-4

This test addresses Chapter 2 crash scenarios that include the following: Distracted driver RE, Inattentive driver RE, and Overhead object (operational scenario).

The countermeasure should provide the required crash alert at a range that is consistent with the alert onset timing requirements of Chapter 4.

5.5.4.2 Track and Prop Setup

Road Geometry and Conditions

Use conditions per Test N-1.

POV Description

POV type: Midsize sedan

Prop Description

Other Objects in the Scene: Overhead sign (see Test N-1).

5.5.4.3 Environmental Conditions Requirements

Use the same conditions as in Test N-1.

5.5.4.4 Instrumentation Requirements

Test Validity

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

Additional instrumentation requirements include:

- The location and orientation of the parked POV in the roadway, as stipulated in the general crash alert requirements.

5.5.4.5 Driving Instructions

The POV should be parked in the lane of travel, as described in Crash Alert Tests General Requirements. The position of the stationary POV should be determined, if necessary. (Only the relative position of the SV with respect to the POV is needed, and some measurement approaches will make absolute knowledge of POV position unnecessary.)

Drive the SV at a nominal speed of 27.8 m/sec (100 kph) in the center of the lane of travel, toward the parked POV. The test begins when the SV is 200m from the POV and ends when either of the following occurs:

- The required crash alert has occurred.
- The range to the POV falls to less than 90% of the minimum allowable range at alert onset, for the required crash alert.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

For the nominal SV speed, the maximum allowed alert onset range is 146.1m and the minimum allowed range for alert onset is 100.0m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than two kph (0.6 m/sec) during the test (with a confidence level of 95%).

- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).
- The SV driver cannot touch the brake pedal before the required crash alert occurs, or before the range falls to less than 90% of the minimum allowed range for onset of the required crash alert.

5.5.5 Test C-5 100 kph to Slowed or Stopped Motorcycle

5.5.5.1 Test Overview and Purpose

This test consists of a SV traveling on a straight, flat road at highway speed toward a stationary POV, which is a motorcycle with a rider. The test examines the countermeasure's ability to issue timely alerts to targets with small sensor cross-sections on an open roadway. The countermeasure should provide the required crash alerts at a range that is consistent with the alert onset timing requirements of Chapter 4. The test data is also used in estimating expected exposure to in-path nuisance alerts for the countermeasure.

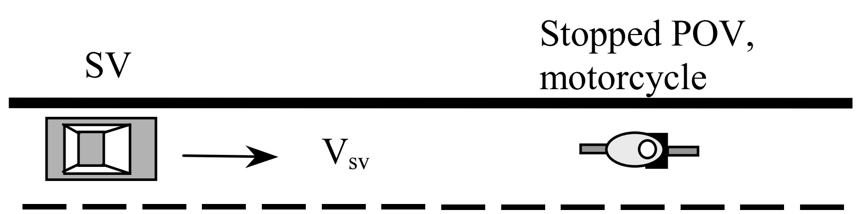

Figure 5-6 Test Maneuver Diagram for Test C-5

This test addresses Chapter 2 crash scenarios that include the following: Distracted driver RE and Inattentive driver RE.

5.5.5.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Description

POV type: Motorcycle with rider.

5.5.5.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.5.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

5.5.5.5 Driving Instructions

The POV should be parked in the lane of travel, as described in Crash Alert Tests General Requirements. The position of the stationary POV should be determined, if necessary. (Only the relative position of the SV with respect to the POV is needed, and certain measurement approaches may make absolute knowledge of POV position unnecessary.)

Drive the SV at a nominal speed of 27.8 m/sec (100 kph) in the center of the lane of travel, toward the parked POV. The test begins when the SV is 200m from the POV and ends when either of the following occurs:

- The required crash alert has occurred.
- The range to the POV falls to less than 90% of the minimum allowed range at the onset of the required crash alert.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

For the nominal SV speed, the maximum allowed alert onset range is 146.1m and the minimum allowed range for alert onset is 100.0m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).

- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).
- The SV driver cannot touch the brake pedal before the required crash alert occurs, or before the range falls to less than 90% of the minimum range allowed for the onset of the crash alert.

5.5.6 Test C-6 Moderate-Speed SV to POV Stopped in Transition to a Curve (Wet Pavement)

5.5.6.1 Test Overview and Purpose

In this test, the SV approaches a POV parked in a zone of transition from a straight road segment to a curved road segment, as shown in Figure 5-7 below. Both vehicles should be near the center of the same lane; the pavement is wet. If successful, the countermeasure should issue the required crash alert at a range consistent with the alert onset timing requirements in Chapter 4. The test data is also used in estimating expected exposure to in-path nuisance alerts for the countermeasure.

The test studies the countermeasure's ability to track targets through changes in curvature. Wet pavement is used to ensure that countermeasures are able to identify curvature changes even in non-ideal situations. This test addresses Chapter 2 crash scenarios that include the Distracted driver RE and Inattentive driver RE scenarios.

5.5.6.2 Track and Prop Setup

Road Geometry and Conditions

Standard values per Section 5.3.3 apply, except the road surface should be wet and the roadway horizontal curvature must meet the requirements given below.

The test site for this test should consist of a straightaway of at least 200m followed by a sudden transition (less than 20m in length) to a constant curvature road section with a radius of curvature between 182 and 300 m. The lane in which the POV is stopped cannot have superelevation greater than 12% deg. (This superelevation limit is the maximum recommended by AASHTO for open highways in regions where snow and ice are not factors (see Policy on Geometric Design of Highways and Streets (1994)). This value is allowed here since proving ground facilities often do not have lower superelevation for curves of this radius.)

POV Descriptions

POV type: Midsize sedan.

5.5.6.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

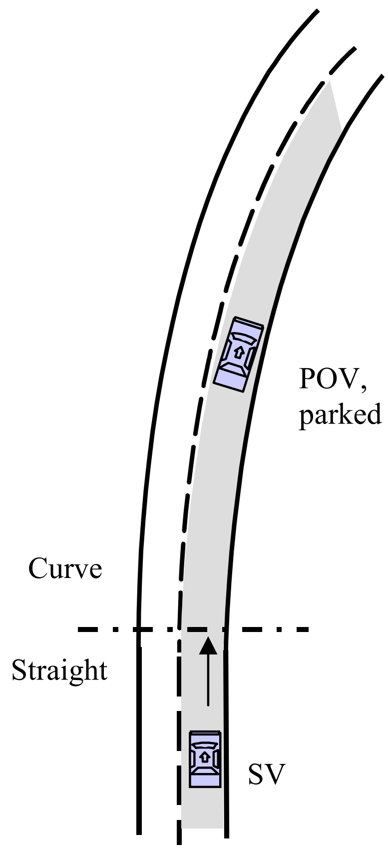

Figure 5-7 Schematic of Test Maneuver for Test C-6

5.5.6.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

Road curvature measurements must provide a 95% confidence that the test site meets specifications.

Instrumentation should support the determination that the POV is placed as required, relative to the transition of curvature, as given below in Driving Instructions.

5.5.6.5 Driving Instructions

The test begins with the POV stopped near the center of a lane of travel at a location just beyond the transition from a straight road segment to a curve. The SV travels at a constant speed, in the same lane as the POV, and approaches along the curve. The alert onset will be required in a region very near the transition, as described below.

The SV vehicle speed and POV location along the road depend on the curvature at the specific test site, as shown in the table below. The dependence on curvature is used to reduce the sensitivity of test results to the specific test site. The values in the table follow from two relationships. First, AASHTO guidelines are used to select the radius of curvatures that correspond to moderate speeds of 65 to 80 kph, which is the range of speeds of interest for the scenario. The radii in the table correspond approximately to the minimum radius recommended for a 4% superelevation curve for the corresponding speeds in the table, and therefore represent challenging but realistic road geometries. The second consideration leads to the required placement of the parked POV down-road from the transition. Based on the curve/speed selection, the POV is placed in slightly different locations. The values shown in the table all provide a maximum azimuth angle (angle between the SV's direction of travel and the line of sight from the SV to the POV) that is approximately the same across the allowed values of radii (8.2 deg). This requires the same sensor coverage to pass the test, independent of the test site.

Radius of curve	**Required SV speed**	**POV placement – rear-end location, down-road from the transition from straight to curve**
182 – 206 m	65 kph	58 m
207 – 250 m	70 kph	68 m
251 – 288 m	75 kph	77 m
288 – 300 m	80 kph	86 m

Table 5-4 Curve and SV Speed Requirements for Test C-6

The test begins when the SV is 150 m from the POV. The test ends when either of the following occurs:

- The required crash alert has occurred.
- The range to the POV falls to less than 90% of the minimum range allowed for the crash alert.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

The range at which alert onset occurs must be consistent with the timing requirements of Chapter 4. Depending on the exact SV speed during a test trial, the latest allowed alert will be somewhere between 60 and 90 m. Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than two kph (0.6 m/sec) (with a confidence level of 95%).

- The lateral distance of the CG of the POV and the heading angle of the POV must meet the requirements for a parked POV test situation, as described in Section 5.4.1.2.

- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).

- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.30 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.30deg) (with a confidence level of 95%).

- The SV driver cannot touch the brake pedal before the required crash alert occurs, or before the range falls to less than 90% of the minimum range allowed for onset of the crash alert.

5.5.7 Test C-7 Highway-Speed SV to POV Stopped in a Curve

5.5.7.1 Test Overview and Purpose

In this test, the SV, traveling through a curve at highway speed, approaches a stationary POV parked near the center of a lane in a curve, as shown below in Figure 5-8. Throughout the test, the SV travels near the center of the lane in which the POV is parked, and the SV remains at constant speed. The lane does not have painted lane markings. The test verifies the countermeasure's ability to identify a threat on a curved road segment without painted lane markings. If successful, the countermeasure would issue the required crash alert at a range consistent with the alert onset timing requirements of Chapter 4. The test data is also used in estimating expected exposure to in-path nuisance alerts for the countermeasure.

This test addresses Chapter 2 crash scenarios that include the Distracted driver RE and Inattentive driver RE scenarios.

5.5.7.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3, except a moderate value for roadway horizontal curvature is desired, and the test should be run with “no lane markings,” a condition defined in detail in the Definitions section.

The test site for this test should be a constant curvature road section with a radius of curvature between 456 and 700 m. The lane in which the POV is stopped cannot have superelevation greater than 12% deg. (This superelevation limit is the maximum recommendation by AASHTO for open highways in regions where snow and ice are not factors (see Policy on Geometric Design of Highways and Streets (1994)). This value is allowed here since proving ground facilities often do not have lower superelevation for curves of this radius.)

POV Descriptions

POV type: Midsize sedan.

5.5.7.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.7.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

Road curvature measurements must provide a 95% confidence that the test site meets specifications.

5.5.7.5 Driving Instructions

The POV is parked in a curve, at least 400m from the beginning of the curve, near the center of a lane of travel. The SV, traveling in the same lane, approaches the POV at a speed that depends on the test site road curvature, as shown in the table below.

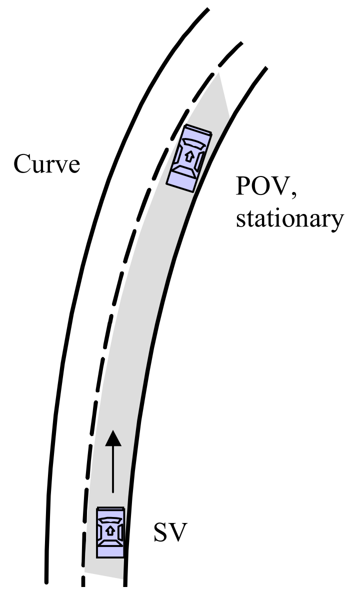

Figure 5-8 Schematic of Test Maneuver for Test C-7

The SV speed depends on the curvature at the test site in order to reduce the sensitivity of test results to the curvature of the test site, but still provide a realistic curvature scenario. Values in the table are chosen using two relationships. First, AASHTO guidelines are used to select radius of curvatures that correspond to speeds of 90 to 110 kph, which is the range of speeds of interest for the scenario. The radii in the table correspond approximately to the minimum radius recommended for a 4% superelevation curve for these speeds, and therefore represent challenging but realistic road geometries. The table shows that the azimuth angle (angle between the SV's direction of travel and the line of sight from the SV to the POV) at a range of 100m varies from approximately 4.1 to 6.3 deg. This variation should not affect repeatability across test sites since a countermeasure will need more azimuth coverage than this to pass another test, Test C-6, which requires approximately 8 deg azimuth to one side of the longitudinal axis.

Radius of curve	**Required SV speed**	**Approximate azimuth angle at 100 m range**
456 – 478 m	95 kph	6.3 deg
479 - 541 m	100 kph	5.7 deg
541 - 641m	105 kph	4.9 deg
640 - 700 m	110 kph	4.1 deg

Table 5-5 Curve and SV Speed Requirements for Test C-7

The test begins when the SV is 200 m from the POV. The test ends when either of the following occurs:

- The required crash alert has occurred.
- The range to the POV falls to less than 90% of the minimum allowed range for onset of the required crash alert.

The alert onset should occur at a range that is between the minimum and maximum allowed values, as described in the alert onset requirements of Chapter 4. These values depend on the actual SV speed during a test trial, but the minimum allowed value is likely to be the 100.0m limit on required warning range. See Appendix B for instructions on computing the alert onset timing requirements as a function of the actual SV speed.

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).
- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.60 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.60deg) (with a confidence level of 95%).
- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum allowable range for onset of the crash alert.

5.5.8 Test C-8 Moderate-Speed SV to Slower Moving POV, in Tight Curve

5.5.8.1 Test Overview and Purpose

In this test, the SV approaches a slower-moving POV in a tight curve. Both vehicles are traveling near the center of the same lane. The test investigates the countermeasure's ability to identify moving targets in tight curvature situations. If successful, the countermeasure would issue the required crash alert at a range consistent with the alert onset timing requirements of Chapter 4. The test data is also used in estimating expected exposure to in-path nuisance alerts for the countermeasure.

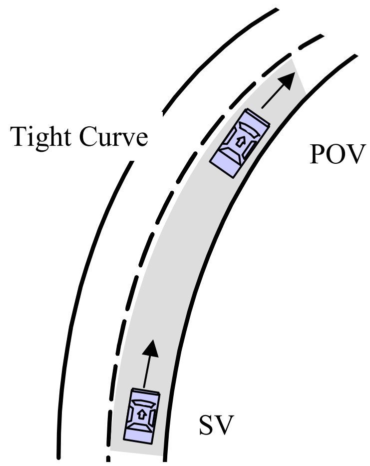

Figure 5-9 Schematic of Test Maneuver for Test C-8

This test addresses Chapter 2 crash scenarios that include the Distracted driver RE and Inattentive driver RE scenarios.

5.5.8.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3, except for the roadway geometry.

The roadway geometry here is intended to represent a relatively tight curve, such as those found on cloverleaf interchanges. The test site for this test should consist of a straightaway of at least 200m followed by a sudden transition to a constant curvature road section with a radius of curvature between 182 and 300 m. The lane in which the POV is stopped cannot have superelevation greater than 12% deg. (This superelevation limit is the maximum allowed by AASHTO standards for public roads (see Policy on Geometric Design of Highways and Streets (1994)). This value is allowed here since proving ground facilities often do not have lower superelevation curves of this radius.)

POV Descriptions

POV type: Midsize sedan.

5.5.8.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.8.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

Road curvature measurements must provide a 95% confidence that the test site meets specifications.

5.5.8.5 Driving Instructions

The test begins with the SV and POV each traveling at constant speed near the center of the same travel lane. The initial speed of the SV depends on the curvature of the test site, as described below. The POV speed should be 40kph less than the SV speed. The maneuver should be executed so that the required crash alert is triggered while both vehicles are in the tightly curved section.

The SV speed should be based on the radius of curvature of the test site, as shown in the table below. This dependence is used to reduce the dependence of test results on the specific curvature at a test site, while still testing the countermeasure's performance in a realistic and challenging curve scenario. Values in the table are chosen using two relationships. First, AASHTO guidelines are used to select radius of curvatures that correspond to speeds of 65 to 80 kph, which is the range of speeds of interest for the scenario. The radii in the table correspond approximately to the minimum radius recommended for a 4% superelevation curve for these speeds. The table shows that the azimuth angle (angle between the SV's direction of travel and the line of sight from the SV to the POV) at the minimum allowed range for crash alert onset varies from 2.7 to 4.6 deg. This variation should not affect repeatability across test sites since a countermeasure will need more azimuth coverage than this to pass another test, Test C-6, which requires approximately 8 deg azimuth to one side of the longitudinal axis.

Radius of curve	Required SV speed	Required POV speed	Approximate azimuth angle at minimum allowed range for alert onset
182 – 206 m	65 kph	25 kph	4.6 deg
207 – 250 m	70 kph	30 kph	3.7 deg
251 – 288 m	75 kph	35 kph	3.1 deg
288 – 300 m	80 kph	40 kph	2.7 deg

Table 5-6 Curve and SV Speed Requirements for Test C-8

The test begins when the SV is 150 m from the POV. The test ends when either of the following occurs:

- The required crash alert has occurred.

- The range to the POV falls to less than 90% of the minimum range allowed at onset of the crash alert.

The onset of the crash alert should occur at a range that is between the minimum and maximum allowed alert onset distances, per the alert onset timing requirements of Chapter 4. Appendix B gives instructions for computing the alert onset timing requirements as a function of the speeds and accelerations of the vehicles during an actual test trial.

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).

- The POV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).

- The lateral distance of the CG of the POV, relative to the center of the lane, in road coordinates, cannot exceed 0.30m (with a confidence level of 95%).

- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).

- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.60 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.60deg) (with a confidence level of 95%).

- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum allowed range at onset of the required crash alert.

5.5.9 Test C-9 POV at 67 kph Cuts in Front of 100 kph SV

5.5.9.1 Test Overview and Purpose

In this test, the SV is initially traveling at constant speed in a given lane on a straight, flat road. A slower-moving POV, which is initially traveling in an adjacent lane, changes lanes so that it cuts in front of the SV.

The test determines whether the countermeasure crash alert occurs at an appropriate times. The appropriate time is a function of both the lateral position of the POV, relative to the SV, and the combination of range, range rate, and relative longitudinal acceleration between the two vehicles. The requirements are described in the alert onset timing requirements section of Chapter 4. The test data is also used in estimating expected exposure to in-path nuisance alerts for the countermeasure.

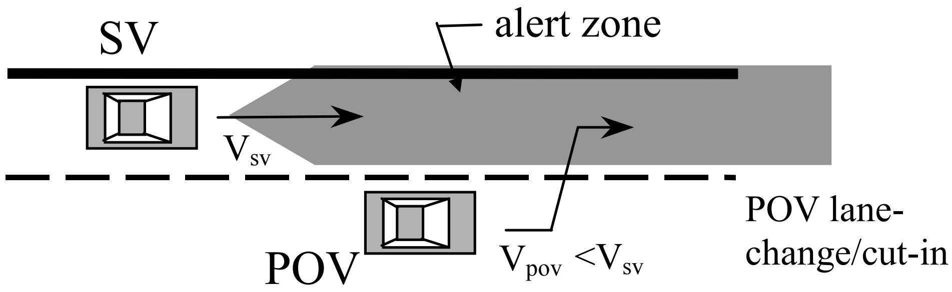

Figure 5-10 Test Maneuver Diagrams for Test C-9

This test addresses the Chapter 2 crash scenario: Lane Change RE (POV cut-in).

Criteria for Successful Countermeasure Performance

Chapter 4 describes the Alert Zone and the alert onset timing requirements. Given a test trial that meets the requirements given below, the onset of the crash alert must not violate either the requirements on allowable lateral locations of targets or the requirements on alert onset timing.

5.5.9.2 Track and Prop Setup

Roadway Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Description

POV type: Midsize sedan

5.5.9.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.9.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

5.5.9.5 Driving Instructions

In this test, the SV is initially traveling at a constant speed of 27.8 m/sec (100 kph) near the center of a given lane on a straight, flat road. A slower-moving POV (at 18.6 m/sec, or 67 kph), which is initially traveling near the center of an adjacent lane, changes lanes so that it cuts in front of the SV. The closing speed is nominally 9.2 m/sec, or 33 kph. For the nominal speeds, the maximum allowed range at alert onset range is 41.6 m and the minimum allowed range for alert onset is 21.9 m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

The initial lateral offset between the vehicle CGs should be a standard U.S. lane-width (3.66 m), with an allowable deviation of 0.50 m. There should be a confidence level of 95% that this condition is met for a 3.0 sec duration before the POV begins its cut-in.

The SV's Alert Zone is centered about the vehicle longitudinal axis and extends symmetrically to a width of 3.66m, as described in Chapter 4. The part of the SV's Alert Zone in which a crash alert must occur (assuming appropriate relative motion in the longitudinal direction) extends laterally to the edge of the SV's physical boundary. When the POV first begins to enter the Alert Zone, the range from the SV to the POV should be between 32m and 42m (95% confidence required). When entering the Alert Zone, the lateral speed of the POV should be between 0.75 and 1.5 m/sec, measured in the roadway coordinates. The POV should cross laterally into the part of the Alert Zone in which alerts are required at a range of between 24m and 34m.

The test begins when the SV is 90 m from the POV and ends when either of the following occurs:

- The required crash alert has occurred.
- The range to the POV falls to less than 90% of the minimum range allowed for the onset of the crash alert.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

For the trial to be valid, the following must hold for the duration of the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).

- The POV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The variation in the lateral distance of the CG of the SV, relative to the travel lane centerline, cannot exceed 0.50 m (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).
- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum allowed range for the onset of the crash alert.

5.5.10 Test C-10 SV at 72 kph Changes Lanes and Encounters Stopped POV

5.5.10.1 Test Overview and Purpose

This test begins with a SV traveling at 72 kph near the center of a lane on a straight, flat road. A stationary POV is parked in an adjacent lane. When the SV is not far from the parked POV, it abruptly changes lanes, in an imitation of an aggressive driver. The test examines the countermeasure's ability to quickly identify threats and warn the driver in situations in which the SV itself is performing maneuvers. This test addresses the Aggressive driver RE crash scenario.

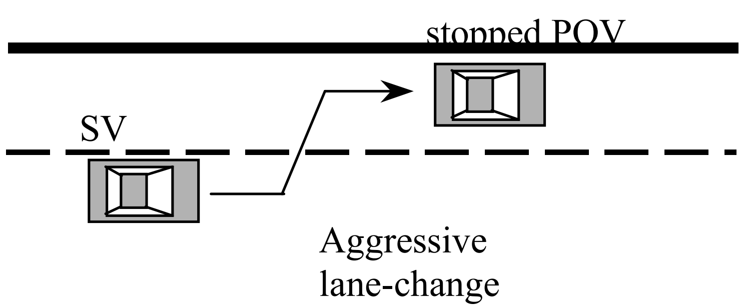

Figure 5-11 Test Maneuver Diagram for Test C-10

Criteria for Successful Countermeasure Performance

The countermeasure should provide the required crash alert when two conditions are satisfied: (1) the range to the POV is within the bounds of the alert onset timing requirements (Chapter 4), and (2) the POV has crossed laterally into that part of the Alert Zone in which crash alerts are required when condition (1) is satisfied. (See Chapter 4 for a description of the regions of the Alert Zone in which the crash alert is required, allowed, and not allowed.)

The test data is also used in estimating expected exposure to in-path nuisance alerts for the countermeasure.

5.5.10.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Descriptions

POV type: Midsize sedan.

5.5.10.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.10.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

Instrumentation needs for this test also include measuring:

- Location and orientation of the parked POV with respect to either the lane of travel, or the roadway, whichever applies, as stipulated in the general crash alert requirements.

5.5.10.5 Driving Instructions

The POV should be parked in the lane of travel, as described in Crash Alert Tests General Requirements. The position of the stationary POV should be determined, if necessary. (Only the relative position of the SV with respect to the POV is needed, and certain measurement approaches may make absolute knowledge of POV position unnecessary.)

Drive the SV toward the parked POV at a nominal speed of 20.0 m/sec (72 kph); the SV should be kept near the center of a lane adjacent to the lane in which the stopped POV is parked. The SV should change lanes early enough so that there is overlap in the lateral direction between the edges of the SV and the POV at a range of more than 100m, but less than 120m. The test begins when the SV is still 200m from the POV and ends when either of the following occurs:

- The required crash alert occurs.
- The range to the POV falls to less than 90% of the minimum range allowed for the onset of the crash alert.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

For the nominal SV speed, the alert onset timing requirements of Chapter 4 call for the alert to begin at a range that is between 77.9 and 94.2 m.

For the trial to be valid, the following must hold throughout the entire test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum range allowed for the onset of the crash alert.

In addition, the following must hold in the initial few seconds of the test, before the SV begins to change lanes:

- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 3.66+0.50m = 4.16m (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).

Finally, the SV lane-change should be such that:

- When the SV is within 70m of the POV, the lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot be larger than 0.50 m (with a confidence level of 95%).

5.5.11 Test C-11 100 kph to Stopped POV, With Fog

5.5.11.1 Test Overview and Purpose

This test consists of a SV traveling on a straight, flat road at highway speed toward a vehicle which is stopped in the middle of the lane of travel. The atmospheric visibility is poor, due to fog. The test investigates whether the countermeasure complies with the minimum functional requirement (from Chapter 4) that states that the FCW must either (1) operate without reduced operating range, or (2) signal the driver that it is unable to function to its fullest operating range

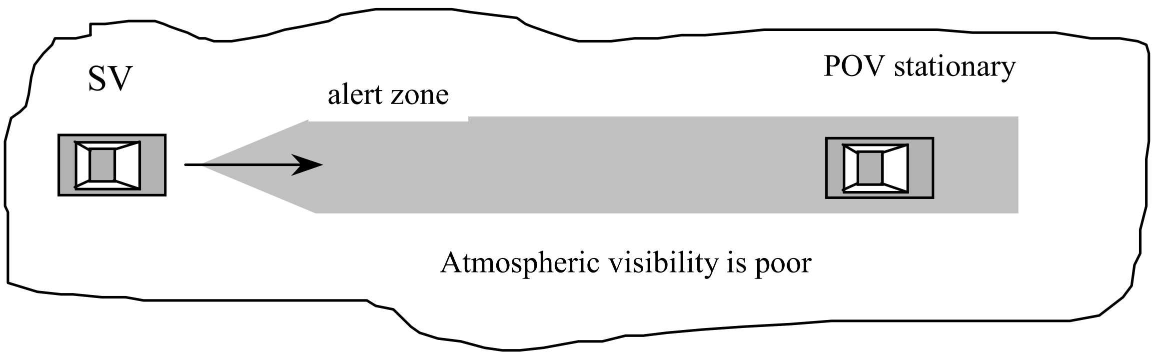

Figure 5-12 Test Maneuver Diagram for Test C-11

This test addresses the Chapter 2 crash scenario: Visibility RE

Criteria for Success of Test

The countermeasure should have one of two responses. The first acceptable response is that the countermeasure provides the crash alert such that its onset is consistent with the timing requirements of Chapter 4, and is within 10% of the nominal warning ranges the system has under these conditions (see Test C-1). The second acceptable response is that the system signals the driver that it cannot operate to its full operating range.

5.5.11.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3, except – due to the need for fog – the roadway is allowed to be wet if necessary, as long as the safety of the test is not compromised

POV Descriptions

POV type: Midsize sedan

5.5.11.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2, except the atmospheric visibility should be poor (see Definitions for a precise description of allowable visibility measures). For this test, the visibility should be poor due to naturally occurring or artificially created fog.

5.5.11.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

Additional instrumentation requirements for this test include:

- Location and orientation of the parked POV with respect to either the lane of travel, or the roadway, whichever applies, as stipulated in the general crash alert requirements.

Instrumentation should support that the local atmospheric conditions satisfy the definition of "poor visibility," as described in Definitions. This will involve a measurement of the instantaneous visibility at the specific testing site. Also, it is necessary to detect whether the countermeasure signals the driver that it is unable to function to its full range due to the reduced visibility. Determining whether the system is signaling in such a way can be a manual function requiring no instrumentation.

5.5.11.5 Driving Instructions

The POV should be parked in the lane of travel, as described in Crash Alert Tests General Requirements. The position of the stationary POV should be determined, if necessary. (Only the relative position of the SV with respect to the POV is needed, and some measurement approaches will make absolute knowledge of POV position unnecessary.) Atmospheric visibility should be "poor," as defined in the Definitions section.

Drive the SV at a nominal speed of 27.8 m/sec (100 kph) in the center of the lane of travel, toward the parked POV. The test begins when the SV is 200m from the POV and ends when any of the following occurs:

- The required crash alert occurs.

- The range to the POV falls to less than 90% of the minimum range allowable for the onset of the crash alert.

- The countermeasure signals the driver that it cannot operate at its full range.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

For the nominal SV speed, the maximum allowed range at alert onset is 146.1m and the minimum allowed range for alert onset is 100.0m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.) For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).

- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).

- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).

- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum range allowed for the onset of the crash alert.

5.5.12 Test C-12 POV Brakes While SV Tailgates at 100 kph

5.5.12.1 Test Overview and Purpose

This test begins with a SV following a POV that is traveling at constant speed on a straight, flat road. The POV begins to brake while the SV maintains its speed. The test determines whether the countermeasure issues the crash alert with a timing that is consistent with the alert onset timing requirements described in Chapter 4. This test especially explores the ability of the countermeasure to issue timely warnings with a decelerating lead vehicle (see also Test C-3.) The test data is also used to estimate the expected exposure to in-path nuisance alerts for the countermeasure.

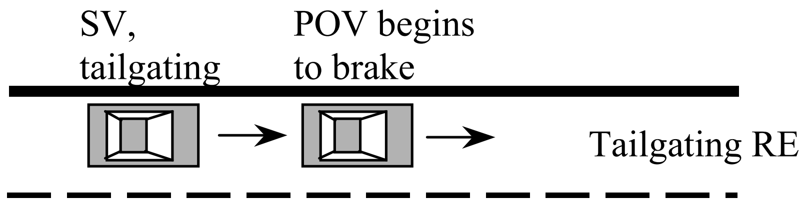

Figure 5-13 Test Maneuver Diagram for Test C-12

This test addresses the Chapter 2 crash scenario: Tailgate RE

5.5.12.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Descriptions

POV type: Midsize sedan

5.5.12.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.12.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

5.5.12.5 Driving Instructions

Drive the POV at a nominal speed of 27.8 m/sec (100 kph) in the center of the lane of travel. The SV should also be at the same constant speed, at a headway of 1.0 seconds. After this configuration is held for at least 5.0 seconds, the POV should begin a deceleration with a nominal value of –0.15g. The test ends when one of the following occurs:

- The required crash alert occurs.

- The range to the POV falls to less than 90% of the minimum range allowable for onset of the required crash alert.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

For the nominal initial speeds and assuming an *ideal* POV braking profile – a step change from constant speed to -0.15g – the maximum allowable range for onset of the crash alert would be 24.9 m and the minimum allowed range at alert onset would be 17.9 m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold before the POV braking maneuver begins:

- The POV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).

- The headway between the SV and POV, during the seven seconds before the POV begins to brake, should be between 0.85 to 1.15 seconds.

The braking profile of the POV must satisfy the following:

- 1.5 seconds after the POV begins to decelerate, its deceleration should remain within 0.03 g of the nominal deceleration level of –0.15g. This should continue until the test is over (see above for definition of the end of the test).

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).

- The lateral position of the CG of the POV, relative to the road edge, cannot exceed 0.30 m (with a confidence level of 95%).

- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).

- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).

- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum range allowed at the onset of the crash alert.

5.5.13 Test C-13 Greater Size and Equal Distance

5.5.13.1 Test Overview and Purpose

This test includes a POV with a small sensor cross-section (a motorcycle) traveling between two POVs with large sensor cross-sections (trucks). All three POVs are traveling at the same speed and each POV is near the center of its lane, as shown in the figure below. The SV is moving faster, and approaches the three POVs at constant speed while traveling in the same lane as the small sensor cross-section POV. The test determines whether the countermeasure issues the crash alert at a range that is consistent with the alert onset timing requirements of Chapter 4. The test data is also used to estimate expected exposure to in-path nuisance alerts for the countermeasure.

This test is one of two tests that explore the countermeasure's ability to resolve in azimuth a target with a small sensor cross-section, while traveling in traffic. (The other test is an out-of-path nuisance alert test, without the motorcycle.)

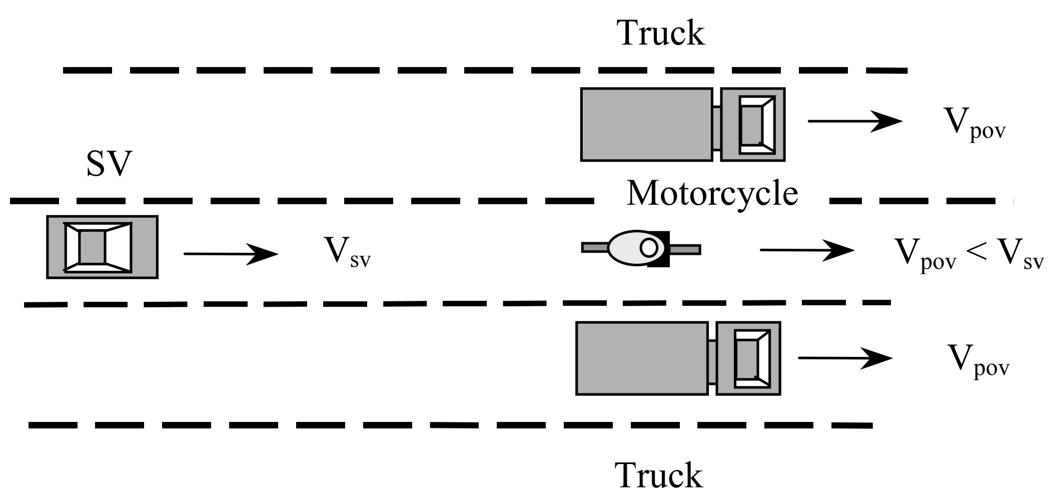

Figure 5-14 Schematic of Test Maneuver for Test C-13

This test addresses Chapter 2 crash scenarios Distracted driver RE and Inattentive driver RE, as well as the operational scenario Greater size and Equal Distance RE.

5.5.13.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Descriptions

POV types: Trucks (2), Motorcycle (1).

5.5.13.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.13.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

5.5.13.5 Driving Instructions

The test begins with the three POVs traveling side-by-side at a constant speed of 8.9 m/sec (32 kph), each in the center of their respective lanes of travel. The SV approaches the POVs at 27.8 m/sec (100 kph), also traveling near the center of its lane. The test begins when the SV is 150 m from the POVs. The test ends when either of the following occurs:

- The required crash alert occurs.
- The range to the POV falls to less than 90% of the minimum range allowable for the onset of the required crash alert.

For the nominal speeds, the alert onset range should be between 65.4m and 104.9m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).
- The vehicle speed of each of the three POVs cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG’s velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).

- The lateral distance of the CG of the primary POV (the motorcycle), relative to the centerline of its respective lane, in road coordinates, cannot exceed 0.30 m (with a confidence level of 95%).
- The lateral distance of the CG of the secondary POVs (the trucks), relative to the centerline of its respective lane, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).
- The lateral position of the CG of the SV, relative to the lateral position of the primary POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).
- The longitudinal position of the rear-most point on each of the three vehicles must all fall within 3.0m of each other (with a confidence of 95%).
- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum range allowed for onset of the crash alert.

5.5.14 Test C-14 Greater Size and Greater Distance

5.5.14.1 Test Overview and Purpose

This test includes a POV with a small sensor cross-section (a motorcycle) traveling behind a POV with a large sensor cross-section (a truck). The two POVs are traveling at the same speed and each POV is near the center of the same lane, as shown in the figure below. A faster-moving SV approaches the POVs from behind, at constant speed, traveling in the same lane. The test determines whether the countermeasure can distinguish between the two POVs, identify the motorcycle as the immediate target, and issue the required crash alert at a range consistent with the Chapter 4 alert onset timing requirements. The test data is also to estimate the expected exposure to in-path nuisance alerts for the countermeasure.

This test explores an aspect of the countermeasure's ability to resolve targets with small sensor cross-sections in traffic.

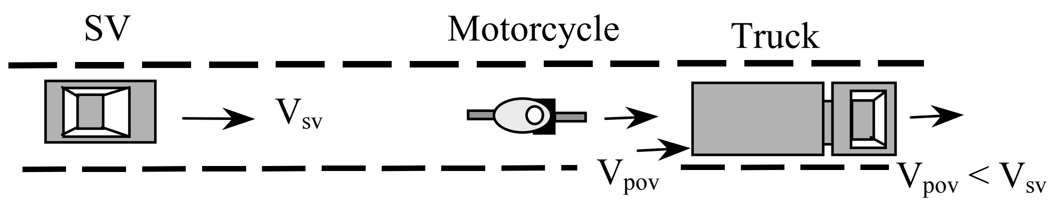

Figure 5-15 Schematic of Test Maneuver for Test C-14

5.5.14.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Descriptions

POV types: Truck (1), Motorcycle (1).

5.5.14.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.14.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

5.5.14.5 Driving Instructions

The test begins with the two POVs each traveling at the same constant speed of 8.9 m/sec (32 kph). The motorcycle follows the truck at a nominal range of 20 m (with tolerances given below), and both POVs remain near the center of the lane of travel.

The SV approaches the POVs at 27.8 m/sec (100 kph), also traveling near the center of the same lane as the POVs. The test begins when the SV is 150 m from the POVs. The test ends when either of the following occurs:

- The required crash alert occurs.

- The range to the POV falls to less than 90% of the minimum range allowed for onset of the crash alert, where the appropriate target is the motorcycle.

For the nominal SV speed, the maximum allowed range at alert onset is 104.9m and the minimum allowed range for alert onset is 65.4m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).

- The vehicle speed of each of the two POVs cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).

- The distance at which the motorcycle follows the truck cannot deviate from the nominal range by more than 5.0m (with a confidence level of 95%).

- The lateral distance of the CG of the SV, relative to the CG of the primary POV (the motorcycle), in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).

- The lateral distance of the CG of the primary POV (the motorcycle), relative to the centerline of its respective lane, in road coordinates, cannot exceed 0.30 m (with a confidence level of 95%).

- The lateral distance of the CG of the secondary POVs (the trucks), relative to the centerline of its respective lane, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).

- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).

- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum range allowed for onset of the required crash alert.

5.5.15 Test C-15 100 kph to 32 kph Truck

5.5.15.1 Test Overview and Purpose

This test includes a POV with a large sensor cross-section (a truck). A faster-moving SV approaches the POVs from behind, at constant speed, traveling in the same lane. This test serves as a complement to Test C-14, since this test determines the range at alert onset for the truck alone. For successful performance, the countermeasure should issue the alert at a range consistent with the alert onset timing requirements of Chapter 4. The test data is also used to estimate expected exposure to in-path nuisance alerts for the countermeasure.

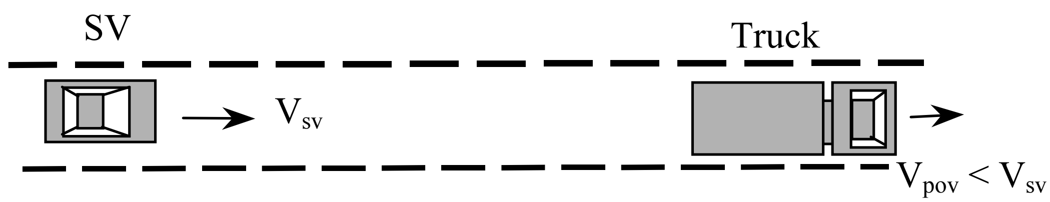

Figure 5-16 Schematic of Test Maneuver for Test C-15

5.5.15.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3.

POV Descriptions

POV types: Truck (1).

5.5.15.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2.

5.5.15.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

5.5.15.5 Driving Instructions

The test begins with the large POV traveling at a constant speed of 8.9 m/sec (32 kph), and remaining near the center of the lane of travel.

The SV approaches the POV at 27.8 m/sec (100 kph), also traveling near the center of the same lane as the POV. The test begins when the SV is 150 m from the POV. The test ends when either of the following occurs:

- The required crash alert occurs.
- The range to the POV falls to less than 90% of the minimum range allowed for the onset of the crash alert.

For the nominal SV speed, the maximum allowed range at alert onset is 104.9m and the minimum allowed range for alert onset is 65.4m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).
- The vehicle speed of each of the POV cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) (with a confidence level of 95%).
- The lateral position of the CG of the POV, relative to the road edge, should not vary by more than 0.30m. (with a confidence level of 95%).
- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).
- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).
- The SV driver cannot touch the brake pedal before either the required crash alert occurs or the range falls to less than 90% of the minimum range allowed at the onset of the required crash alert.

5.5.16 Test C-16 SV to POV Stopped in Transition to Curve (Poor Lane Markings)

5.5.16.1 Test Overview and Purpose

This test is similar to Test C-6, except here the test should be executed on dry pavement with poor lane markings. In this test, the SV approaches a POV stopped in a zone of transition from a straight road segment to a curved road segment, as shown earlier in Figure 5-7. Both vehicles should be near the center of the same lane. The test studies the countermeasure's ability to track targets through changes in curvature. If successful, the countermeasure should issue the required crash alert at a range consistent with the alert onset timing requirements in Chapter 4. The test data is also used in estimating expected exposure to in-path nuisance alerts for the countermeasure.

This is a common driving situation that may challenge some countermeasures' ability to detect curvature changes. This test addresses Chapter 2 crash scenarios that include the Distracted driver RE and Inattentive driver RE scenarios.

5.5.16.2 Track and Prop Setup

Road Geometry and Conditions

Standard values per Section 5.3.3.1 apply, except the roadway horizontal curvature and the quality of the lane markings.

The roadway geometry should meet the same requirements given for Test C-6.

"Poor quality lane markings" should be used. A detailed definition of this condition is given in the Definitions section. Note that good quality lane markings can be made into poor quality lane markings (as defined in this chapter) by obscuring the lane markings, for example, by sand.

POV Descriptions

Same requirements as for Test C-6.

5.5.16.3 Environmental Conditions Requirements

Same requirements as for Test C-6.

5.5.16.4 Instrumentation Requirements

Instrumentation requirements are identical to those of Test C-6.

Countermeasure Performance Evaluation

Same as for Test C-6.

5.5.16.5 Driving Instructions

Same as for Test C-6.

5.5.17 Test C-17 24 kph to Stopped POV

5.5.17.1 Test Overview and Purpose

This test consists of a SV traveling on a straight, flat road at low speed toward a vehicle which is parked in the middle of the lane of travel. The test is to determine whether the countermeasure crash alert onset occurs at a range that is consistent with the alert onset timing requirements described in Chapter 4. The test is also used to estimate the expected exposure to in-path nuisance alerts for the countermeasure.

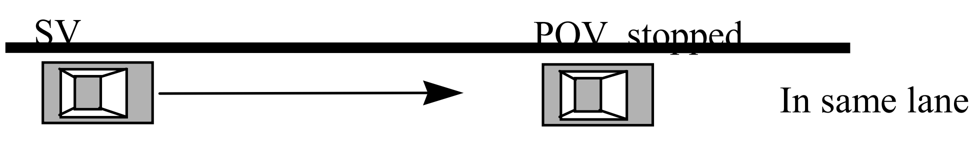

Figure 5-17 Test Maneuver Diagram for Test C-17

This test addresses Chapter 2 crash scenarios that include the following: Distracted driver RE; and Inattentive driver RE.

5.5.17.2 Track and Prop Setup

Road Geometry and Conditions

Use standard conditions, per Section 5.3.3.1.

POV Description

POV type: Midsize sedan

5.5.17.3 Environmental Conditions

Use standard conditions, per Section 5.3.3.2.

5.5.17.4 Instrumentation Requirements

The standard instrumentation requirements for crash alert tests are given in Section 5.4.2.

In addition, instrumentation accuracies should support the determination of whether or not the location and orientation of the stopped POV are as stipulated in the general crash alert requirements.

5.5.17.5 Driving Instructions

The POV should be parked in the lane of travel, as described in Crash Alert Tests General Requirements. The position of the stationary POV should be determined, if necessary. (Only the relative position of the SV with respect to the POV is needed, and some measurement approaches will make absolute knowledge of the POV position unnecessary.)

Drive the SV at a nominal speed of 6.7 m/sec (24 kph) in the center of the lane of travel, toward the parked POV. The test begins when the SV is 100m from the POV and ends when either of the following occurs:

- The required crash alert occurs.
- The range to the POV falls to less than 90% of the minimum allowable range for the onset of the required crash alert.

After one of these events occurs, the SV driver must then steer and/or brake to keep the SV from striking the POV.

For the nominal SV speed, the maximum allowed alert onset range is 21.6m and the minimum allowed range for alert onset for the crash alert is16.5m. (Appendix B gives instructions for computing alert onset timing requirements for the crash alert tests as a function of the actual speeds and accelerations measured during a test trial.)

For the trial to be valid, the following must hold throughout the test:

- The SV vehicle speed cannot deviate from the nominal speed by more than 2 kph (0.6 m/sec) during the test (with a confidence level of 95%).
- The lateral distance of the CG of the SV, relative to the CG of the POV, in road coordinates, cannot exceed 0.50 m (with a confidence level of 95%).

- Either (1) the variation in the heading angle of the SV, measured relative to the travel lane centerline, cannot exceed 0.75 degrees (with a confidence level of 95%), or (2) the variation in the component of the SV CG's velocity normal to the road edge cannot exceed the SV vehicle speed multiplied by sin(0.75deg) (with a confidence level of 95%).

- The SV driver cannot touch the brake pedal before the required crash alert occurs, or before the range falls to less than 90% of the minimum range allowed for onset of the required crash alert.

5.6 Nuisance Alert Test General Requirements

5.6.1 Other Objects in the Scene

The out-of-path nuisance-alert tests should be conducted with no other traffic on the track, except the vehicles needed for the test itself. (Exceptions are allowed if other traffic is more than 400 m from all vehicles during the testing itself). Unless required for the tests, there should be no overhead objects such as signs or bridges near the testing zones. Roadside objects such as signs and markers should be minimized. The locations of roadside objects near the track that cannot be removed should be documented. Unless otherwise required, tests should be run in lanes that are not adjacent to concrete barriers and guardrails.

5.6.2 Instrumentation Requirements

In general, instrumentation and data processing should be adequate to show a 95% confidence level that the setup and execution of each test satisfies the specifications for the test. This includes both the specifications for the vehicle maneuvers and prop setup given with each test.

If an alert occurs the instrumentation and data recording must be adequate to verify that the object(s) that caused the alert were the objects intentionally placed in the scene for the purposes of the test.

5.6.3 Nuisance Alert Test Repetition Requirements

In general, each out-of-path nuisance alert test must be repeated to provide an estimate of the probability that an alert will occur under each test condition. The number of repetitions required depends upon the expected exposure of FCW systems to each combination of conditions. In addition, where appropriate, the out-of-path objects are presented to the FCW system at a variety of distances. Chapter 6 includes a detailed development of the specifications for the required number of repetitions and the required distribution of distances for each out-of-path nuisance-alert test. Briefly, the number of repetitions is designed to expose the FCW system to potential sources of out-of-path nuisances equivalent to 3 weeks worth of driving (approximately 600 miles of driving). The number of trials and the acceptable number of alerts are based upon the projected exposure and a statistical analysis of the number of exposures required to achieve adequate confidence in the test results. The typical exposure estimates are based upon a pilot experimental study performed by CAMP. The details of the pilot experimental study and the statistical analysis are provided in Chapter 6.

5.7 Nuisance Alert Tests

Out-of-path nuisance alert tests investigate the countermeasure's compliance with functional requirements that address operational scenarios. The list of out-of-path nuisance alert tests is given below. Test requirements and procedures are now given for each of these tests.

Out-Of-Path Nuisance Alert Tests	
N-1	Overhead sign at crest of hill
N-2	Road surface objects on flat roads
N-3	Grating at bottom of hill
N-4	Guard-rails and concrete barriers along curve entrance
N-5	Roadside objects along straight and curved roads (dry & wet pavement)
N-6	U-turn with sign directly ahead
N-7	Slow cars in adjacent lane, in transition to curve
N-8	120 kph between two 60 kph trucks in both adjacent lanes
N-9	Slow cars in adjacent lane at a curve (poor lane markings)

Table 5-7 List of Out-of-Path Nuisance-Alert Tests

5.7.1 Test N-1: Overhead Sign at Crest of a Hill

5.7.1.1 Test Overview and Purpose

This test is used to determine the sensitivity of an FCW system to objects commonly found over the traffic lanes of roads. The test covers the difficult condition wherein a crest curve causes the overhead object to appear directly ahead of the SV. The test is conducted using an overhead sign, which is used to representative both signs and bridges commonly found over urban and rural roads.

This test also verifies that the Alert Zone is at least as high as the top of the vehicle.

When the sign is at normal heights, the countermeasure should not produce alerts as the SV approaches and then passes under the overhead object. When the sign is set just above the height of the vehicle an alert should occur as the SV approaches the sign. The results of this test are to be compared with Test C-4, 100 kph to POV stopped under overhead sign, in which an alert is required to occur.

5.7.1.2 Track and Prop Setup

Roadway Geometry and Conditions

Select a hill with a vertical curvature that allows the sign to be directly ahead of the SV as the SV approaches the crest. The preferred vertical curvature is the 15^{th} percentile for vertical curves on public roads. The actual vertical curvature of the track should be measured before testing begins. The horizontal curvature, superelevation, and crown of the track should meet the definition of a straight road.

The maximum vertical curvature will determine the speed at which the SV is driven over the hill. The track should be long enough so that the SV can reach the desired speed before coming within 200 m of the test object.

Use the following table to determine the speed at which the test is run. Choose the speed that is associated with the entry in the table that is closest to the minimum value of K found on the crest curve.

Rate of Vertical Curvature, K, (length (m) per % change in grade)	SV Speed (km/h)
3	30
5	40
9	50
14	60
22	70
32	80
43	90
62	100
80	110
102	120

Table 5-8 Vertical Curvature and SV Speed Requirements for Test N-1

Overhead Sign

This test requires an overhead sign that is similar in both optical and radar characteristics to the large direction and intersection information signs found on interstate highways. A standard design should be used to minimize variation in test results. Until a standard design is developed, the following guidelines are suggested. The sign itself should be approximately 2 m high by 4 m wide. It should be made with a metal back and coated with green retroreflective material with white lettering. There should be a vertical support on either side of the road. The vertical support structure on each side should be constructed using a single cylindrical pole. The horizontal support structure should be constructed from one or two cylindrical poles. If the sign is movable it may be held in place using guy wires that are attached at the top of the vertical poles and extend away from the road.

Place the overhead sign so that it is directly ahead of the SV and perpendicular to its direction of travel as the SV approaches the crest of the hill. Measure the position of the sign relative to the road and crest.

Measure the height of the bottom-center of the sign above the road. Measure the tilt of the sign relative to vertical and the angle of the sign relative to the direction of the road. Document the devices and techniques used to make these measurements.

5.7.1.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2 except run this test with nighttime illumination, as specified in the Definitions section.

5.7.1.4 Instrumentation Requirements

As the SV travels the "testing distance", instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV speed
- Lateral position of the SV relative to the sign, in road coordinates
- Heading angle of the SV relative to the road
- SV brake pedal application (the pedal cannot be applied during testing, since this may disable the alerts for some FCW systems).

5.7.1.5 Driving Instructions

Begin with the SV at a location so that the required speed can be achieved before the SV is within 200 m of the sign. Accelerate to the required speed. Align the SV so that the center of the vehicle is at the same lateral position on the road as the center of the sign. Hold the required speed within ±2 km/h and keep the lateral position within ±0.5 m of the center of the sign until you pass under it. Note whether any alerts are generated by the FCW system.

5.7.1.6 Test Repetitions

The test is repeated with the sign at four different heights using the height and exposure distribution below. To test that the Alert Zone is at least as high as the SV, the test is then repeated once with the sign low enough to be sure an alert occurs but high enough to miss the top of the vehicle and any antennas on the vehicle.

Sign Height Above Road (meters)	4.4-4.65	4.65-4.9	4.9-5.15	5.15-5.4
Average Exposure per day	7	7	7	7
Number of Exposures for Test N-1	147	147	147	147

Table 5-9 Overhead Sign Height Exposure Requirements for Test N-1

5.7.1.7 Data Reporting and Analysis

Data reported must demonstrate the validity of the test run. The reported measurements and analysis must demonstrate the following:

1. The road geometry met the requirements for the test

2. The SV speed was within the required limits for the vertical curvature from the time it came within 200 m of the sign until it passed under it.

3. The SV lateral offset was within the specified limits from the time the SV came within 200 m of the sign until it passed under it.

If an alert occurs, the data analysis and reporting must demonstrate whether the sign caused it.

5.7.2 Test N-2: Road Surface Objects on Flat Roads

5.7.2.1 Test Overview and Purpose

This test is used to determine the sensitivity of an FCW system to road surface markings and small objects that vehicles frequently drive over. The representative objects include lane-marking retro-reflectors, a railroad crossing or similar painted marking, tire debris, beverage cans, and a piece of wood. The test is conducted on a straight section of track.

The countermeasure should not produce alerts as the SV approaches and then drives over these objects.

5.7.2.2 Track and Prop Setup

Roadway Geometry and Conditions

Select a flat, straight, track that is at least two lanes wide and 0.5 km long. The horizontal curvature, vertical curvature, superelevation, and crown of the track should meet the definition of a straight, flat road.

Retroreflectors and Road Surface Markings

The retroreflectors should have optical characteristics equivalent to those of Stimsonite Model 88AW white construction-work-zone markers.

There should be retroreflectors along both sides of the test lane at approximately 80-ft. intervals consistent with lane demarcation. If there are also lines delineating lane boundaries they should be broken lines with dimensions in accordance with Chapter 3 ("Markings") of the U.S. DOT Federal Highway Administration's Manual of Uniform Traffic Control Devices (see References). The MUTCD suggests lines that are 4" to 6" wide with broken lines formed by segments and gaps in a 1:3 ratio (typically 10-foot segments and 30-foot gaps).

There should be 2 separate regions; one with retroreflectors interspersed between white lane markings (3 m white paint lines separated by 9 m spaces), a second with retroreflectors spaced as in the first but without the markings. Each region should be at least 100 m long.

There should be a railroad crossing or similarly sized sign on the surface using highly reflective adhesive tape or paint (see Figure 5-18). The sign should conform to the shape and size guidelines as suggested in the MUTCD.

Survey the locations of the line segments and retroreflectors. Document the devices and techniques used to make these measurements.

Debris

Place a beverage can, piece of tire, and a piece of wood along the lane with at least 100 m separation.

The beverage can should be an empty 12 fl. oz. (355 ml) can that is not crushed. Place the can in the center of a lane so that the axis of the cylinder is horizontal and perpendicular to the direction of travel. The can may be held in place as long as the mechanism is not visible from the vehicle as it approaches the can.

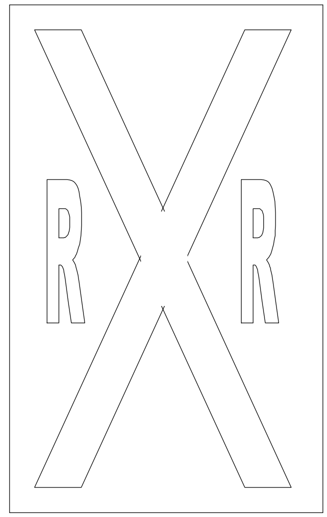

Figure 5-18 Typical Railroad Crossing Warning on Pavement

The piece of tire should be a section of truck tire tread 30 cm long by 10 cm wide. Place the piece of tire in the center of the lane so that it rests naturally on the road with its long axis perpendicular to the direction of travel.

The piece of wood should be approximately 2 cm by 5 cm by 30 cm. Place it in the center of the lane so that its long axis is horizontal and perpendicular to the direction of travel.

Measure the location of each piece of debris. Document the devices and techniques used to make these measurements.

5.7.2.3 Environmental Conditions Requirements

Use standard conditions, per Section 5.3.3.2 except run this test at night.

5.7.2.4 Instrumentation Requirements

As the SV travels the "testing distance", instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV speed.
- Lateral position of the SV relative to the debris and retroreflectors, in road coordinates.

- SV brake pedal application (the pedal cannot be applied during testing, since this may disable the alerts for some FCW systems).

5.7.2.5 Driving Instructions

Begin at a location so that the required speed can be achieved before you are within 200 m of the first debris item. Accelerate to 100 km/h while following the center of the test lane. Hold the speed within ±2 km/h of 100 km/h as you drive through the testing distance. After entering the "testing distance" drive the car in a weaving pattern so that it passes completely into the next lane and back, going over the retroreflectors. Drive the car over each of the pieces of debris so that they pass approximately under the center of the vehicle.

Note whether any alerts are generated by the FCW system.

5.7.2.6 Test Repetitions

The following table indicates an estimated distribution for exposure to road surface objects during a typical day of driving and the resulting number of exposures that should be used in the tests. The number of times the FCW system is run through the course will depend upon the number of reflectors and debris passed each time.

	Road Surface Retroreflectors	**Debris**
Average Exposure Per Day	100	0.5
Number of Exposures for Test N-2	2100	11

The number of trial exposures for each type of object (retroreflectors or debris) is the number of each type of object on the course multiplied by the number of passes through the course.

5.7.2.7 Data Reporting and Analysis

Data reported must demonstrate the validity of the test run. The reported measurements and analysis must demonstrate the following:

- The road geometry met the requirements for the test
- The retroreflectors and debris were located within the required limits.
- The SV speed was within the required limits from the time it came within 200 m of the test area until it passed the last piece of debris or retroreflector.
- The debris passed under the SV within 0.5 m of the front-center of the vehicle.

- The SV passed over at least 4 retroreflectors.

If an alert occurs the data analysis and reporting must demonstrate which retroreflector or piece of debris caused it.

5.7.3 Test N-3: Grating at Bottom of Hill

5.7.3.1 Test Overview and Purpose

This test is used to determine the sensitivity of an FCW system to metal road surface objects, such as a grating, that vehicles frequently drive over. The test is conducted under the difficult condition where a sag vertical curve increases the visibility of the road surface ahead of the FCW system.

The countermeasure should not produce alerts as the SV approaches and then drives over the grating.

5.7.3.2 Track and Prop Setup

Roadway Geometry and Conditions

Select a section of track that has a sag curve. The preferred a change of grade is the 85th percentile for the change of grade in sag curves on public roads. The preferred vertical curvature is the 15th percentile for vertical curves on public roads. Measure the vertical curvature of the track before testing begins. The horizontal curvature, superelevation, and crown of the track should meet the definition of a straight road. Document the devices and techniques used to make these measurements.

The maximum vertical curvature will determine the speed at which the SV is driven over the curve. The track should be long enough so that the SV can reach the desired speed before coming within 200 m of the test object that is placed just after the sag curve.

Use the following table to determine the speed at which the test is run. Choose the speed that is associated with the entry in the table closest to the minimum value of K found on the sag curve.

Rate of Vertical Curvature, K, (length (m) per % change in grade)	SV Speed (km/h)
4	30
8	40
11	50
15	60
20	70
25	80
30	90
37	100
43	110
50	120

Table 5-10 Overhead Sign Height Exposure Requirements for Test N-3

Grating

This test requires a road surface that is similar in both optical and radar characteristics to the metal grating sometimes used on bridges over rivers. A standard design should be used to minimize variation in test results. Until a standard design is developed the following guidelines are suggested. The grating itself should be at least as wide as the lane and at least the length of a car. It should be made with metal slats running perpendicular to the road direction. The grating should be of a thickness common to those used for bridges (perhaps 2 or 3 cm). A shallow wedge shaped ramp should be put in front of the grating so that the front edge of the grating is not exposed to the FCW sensor as the SV approaches it and so that the SV can easily drive over the grating.

Place the grating immediately after the location with the maximum vertical curvature so that it is directly ahead of the SV and perpendicular to its direction of travel as the SV approaches the sag curve. Measure the position of the grating relative to the road and sag curve. Document the devices and techniques used to make these measurements.

5.7.3.3 Environmental Conditions Requirements

Use standard conditions per Section 5.3.3.2.

5.7.3.4 Instrumentation Requirements

As the SV travels the "testing distance", instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV speed
- Lateral position relative to the grating, in road coordinates
- Heading angle of the SV relative to the road.
- SV brake pedal application (the pedal cannot be applied during testing, since this may disable the alerts for some FCW systems).

5.7.3.5 Driving Instructions

Begin at a location so that the required speed can be achieved before you are within 200 m of the grating. Accelerate to the required speed. Align the car so that it is on the road so that its center of the vehicle is at the same lateral position on the road as the center of the grating. Hold the required speed within ±2 km/h and keep the lateral position within ±0.5 m of the center of the grating until you pass over it. Note whether any alerts are generated by the FCW system.

5.7.3.6 Test Repetitions

The following table indicates an estimated distribution for exposure to gratings in a road during a typical day of driving and the resulting number of exposures that should be used in the tests.

	Gratings In Road
Average Exposure per Day	1
Number of Exposures for Test N-3	21

5.7.3.7 Data Reporting and Analysis

Data reported must demonstrate the validity of the test run. The reported measurements and analysis must demonstrate the following:

- The road geometry met the requirements for the test
- The SV speed was within the required limits for the vertical curvature from the time it came within 200 m of the grating until it passed over it.

- The SV lateral offset was within the specified limits from the time the SV came within 200 m of the grating until it passed over it.

If an alert occurs the data analysis and reporting must demonstrate whether the grating caused it.

5.7.4 Test N-4: Guardrails and Concrete Barriers

5.7.4.1 Test Overview and Purpose

This test is used to determine the sensitivity of an FCW system to roadside barriers that vehicles frequently pass. The representative barriers include metal guardrails and concrete dividers. The test is conducted on a section of track that transitions from straight to curved to represent the difficult conditions of a highway exit where the barriers are directly in front of the vehicle as it approaches the curve.

The countermeasure should not produce alerts as the SV approaches and then drives past these objects.

5.7.4.2 Track and Prop Setup

Roadway Geometry and Conditions

Select a track that includes a flat, straight section that transitions to a curve. The straight section should be long enough so that the SV can reach the desired speed before coming within 200 m of the roadside barriers. The preferred minimum radius of curvature in the curve is the 15th percentile for curves in highway interchanges that use a cloverleaf. The curve should be at least 90 degrees with a superelevation of no more than 4%. Current engineering judgment suggests this radius of curvature should be appropriate for a design speed of 50 km/h to 70 km/h. According to AASHTO guidelines this corresponds to radius of curvature values from 100 m (for 50 kph with 4% superelevation) to a curvature of 2000 m (for 70 kph with no superelevation). For additional details on the relationship between design speed, superelevation, and radius of curvature, see Tables III-7 to III-11 of the AASHTO Policy on Geometric Design of Highways and Streets (1994).

Survey the road to determine the actual minimum radius of curvature and superelevation of the curve. The actual minimum radius of curvature in the turn will determine the speed at which the SV is driven around the curve. Determine the design speed for the measured combination of minimum radius of curvature and superelevation.

Barriers

The concrete barrier should be placed alongside the straight part of the track for a length of 50 m that ends just before the curve. The barrier should start at a safe distance from the side of the lane (for the start of a barrier). It should taper toward the lane to a distance equivalent to the 15th percentile of the distance of concrete barriers from traffic lanes on public roads (thought to be about 1m).

The concrete barrier should include retroreflectors that extend from the side approximately every 12 m at an elevation of approximately 1 m from the road.

The metal barrier for this test should have optical and radar characteristics similar to semi-rigid longitudinal barriers used along highways and major arteries to redirect errant vehicles. A standard design should be used to minimize variation in test results. Until a standard design is developed the following guidelines are suggested. The barrier should be constructed with wooden posts and a metal cushion. The cushion should be the same height above the road surface as is typical for this kind of barrier (thought to be about 20 cm). Reflectors should be placed on the cushion approximately every 12 m. The barrier may be built in sections and with a plate at the bottom of each post so that it is portable. The plates must be of a design that does not significantly change the optical or radar characteristics of the mailbox.

The metal barrier should be placed on the outside of the curve. The metal barrier should begin before the beginning of the curve and extend at least far enough so that it is directly ahead of the vehicle as it approaches on the straight part of the track. The beginning of the barrier should be a safe distance from the side of the lane. It should taper to the 15th percentile of distances of barrier from traffic lanes on cloverleaf intersections (thought to be 3m).

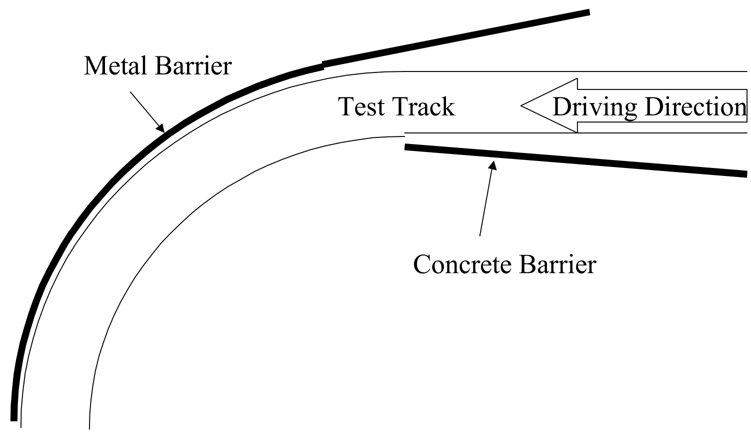

Figure 5-19 Barriers on Curve

The design and location of the barriers must be documented. Document the devices and techniques used to measure the locations of the barriers relative to the roadway.

5.7.4.3 Environmental Conditions Requirements

Use standard conditions per Section 5.3.3.2.

5.7.4.4 Instrumentation Requirements

As the SV travels the "testing distance", instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV speed
- Lateral position of the SV relative to the lane in road coordinates
- SV brake pedal application (the pedal cannot be applied during testing, since this may disable the alerts for some FCW systems).

5.7.4.5 Driving Instructions

Begin at a location so that the required speed can be achieved before you are within 200 m of the concrete barrier. Accelerate to the required speed. Align the car so that it is in the center of the lane. Hold the speed within ±2 km/h of the design speed of the curve and keep the center of the car within ±0.5 m of the center of the lane. Follow the lane until you have passed turned 90 degrees through the curve.

Note whether any alerts are generated by the FCW system.

5.7.4.6 Test Repetitions

The following table indicates an estimated distribution for exposure to guardrails and barriers during a typical day of driving and the resulting number of exposures that should be used in the tests.

Distance of object from Alert Zone (meters)	0.5-1.5	1.5-2.5	2.5 to 3.5	3.5 to 4.5
Guardrails (typical exposure per day)	5	5	5	5
Number of Guardrail Exposures for Test N-4	105	105	105	105
Concrete Barriers (typical exposure per day)	1	1	1	1
Concrete Barrier Exposures for Test N-4	21	21	21	21

Table 5-11 Requirements for Exposure to Extended Roadside Objects for Test N-5

5.7.4.7 Data Reporting and Analysis

Data reported must demonstrate the validity of the test run. The reported measurements and analysis must demonstrate the following:

- The road geometry and barrier locations met the requirements for the test
- The SV speed was within the required limits for the horizontal curvature and superelevation of the curve from the time it came within 200 m of the first barrier until it passed through 90 degrees of the curve
- The SV lateral offset was within the specified limits from the time the SV came within 200 m of the first barrier until it passed through 90 degrees of the curve.

If an alert occurs the data analysis and reporting must demonstrate whether one of the barriers caused it. If one of the barriers caused the alert the data analysis and reporting must determine whether the alert occurred on the straight road, in the transition, or along the curve.

5.7.5 Test N-5: Roadside Objects by Straight and Curved Roads

5.7.5.1 Test Overview and Purpose

This test is used to determine the sensitivity of an FCW system to common roadside objects that vehicles frequently pass. The representative objects include small and large signs, mailboxes, and construction barricades. The test is conducted on a track that includes straight and curved sections. The placement of the objects is as close to the road as permitted for business and residential districts under the FHWA Manual on Uniform Traffic Control Devices (see References)

The countermeasure should not produce alerts as the SV approaches and then drives past these objects.

5.7.5.2 Track and Prop Setup

Roadway Geometry and Conditions

Select a track that includes a flat, straight section that transitions to a curve. The straight section should be long enough so that the SV can reach the desired speed before coming within 200 m of the roadside props. The preferred radius of curvature in the curve is the 15th percentile for curves on roads in residential and business districts. The curve should be at least 90 degrees.. The rate of curve should be the 95th percentile in terms of degrees of turn per 100m on public roads. Current engineering judgment suggests this radius of curvature should be appropriate for a design speed of 40 km/h to 60 km/h. The AASHTO Policy on Geometric Design of Highways and Streets recommends that the minimum radius of curvature for roads designed for these speeds are 800 m to 1520 m when there is no superelevation.

Survey the road to determine the actual minimum radius of curvature and superelevation of the curve. The actual minimum radius of curvature in the turn will determine the speed at which the SV is driven around the curve. Determine the design speed for the measured combination of minimum radius of curvature and superelevation.

At least 15% of the length of the test course should have “no lane markings.” This condition is defined in detail in the Definitions section. Any testing that occurs near transitions in curvature should have “good quality painted lane markings,” per the Definitions section.

Props

The mailboxes for this test should have optical and radar characteristics similar to roadside mailboxes used along residential streets in suburban and rural areas. A standard design should be used to minimize variation in test results. Until a standard design is developed or a particular manufacturers part number is selected, the following guidelines are suggested. The mailbox should be of metal construction approved by the U.S. postal service. Seven digits of reflective numbering at least 5 cm high should be put on the side facing traffic. The mailboxes should be mounted on a 1.5 m vertical wooden post. A base may be attached to the post so that the mailbox is portable. The base must be of a design that does not significantly change the optical or radar characteristics of the mailbox.

Mailboxes should be placed every 20 m along the straight and curved part of the track. The mailboxes should be placed so that the front of the mailbox is 0.5 m from the edge of the lane.

The construction barricades should be a Type I barricade with an A-frame construction as defined in the FHWA Manual on Uniform Traffic Control Devices (see References). A series of 6 barriers should be placed on either side of the straight part of the track at 20 m intervals. The first one should be at 3 m from the edge of the lane and with subsequent barricades placed a successively closer distances to a minimum of 0.0 m from the lane. Place these barricades perpendicular to the direction of travel.

The signs should correspond to the 85th percentile dimensions for signs found adjacent to public roads. They should be placed every 50 m along the straight and curved part of the track. They should be placed at the 15th percentile distance for signs found along public roads. Tentatively, engineering judgment suggests the signs should be a 24" x 30" no-parking sign and a 36" x 36 " diamond-shaped road-narrows symbol like W4-2 in the FHWA Manual on Uniform Traffic Control Devices (see References). The tentative distance is 0.5 m from the road edge at that Manual's recommended height of 1.5 m measured from the bottom of the sign to the ground.

The design and location of each prop must be documented. Document the devices and techniques used to measure the locations of the props relative to the roadway.

5.7.5.3 Environmental Conditions Requirements

Use standard conditions per Section 5.3.3.2.

5.7.5.4 Instrumentation Requirements

As the SV travels the "testing distance", instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV speed.
- Lateral position of the SV relative to the lane in road coordinates.
- SV brake pedal application (the pedal cannot be applied during testing, since this may disable the alerts for some FCW systems).

5.7.5.5 Driving Instructions

Begin at a location so that the required speed can be achieved before you are within 200 m of the first roadside object. Accelerate to the required speed. Align the car so that it is in the center of the lane. Hold the speed within ±2 km/h of the design speed of the curve and keep the center of the car within ±0.5 m of the center of the lane. Follow the lane until you have passed turned 90 degrees through the curve.

Note whether any alerts are generated by the FCW system.

5.7.5.6 Test Repetitions

The following table indicates an estimated distribution for exposure to roadside objects during a typical day of driving.

Distance of Object from Alert Zone (Meters)	0.5-1.5	1.5-2.5	2.5 to 3.5	3.5 to 4.5
Small signs per day	50	50	50	50
Large signs per day	16	16	16	16
Mailboxes per day	11	11	11	11
Construction barricades per day	24	24	24	24

Table 5-12 Estimated Distribution for Exposures to Discrete Roadside Objects

The following table indicates the number of exposures that should be used in the tests. The number of times the FCW system is run through the course will depend upon the number of reflectors and debris passed each time.

Distance of Object from Alert Zone (Meters)	0.5-1.5	1.5-2.5	2.5 to 3.5	3.5 to 4.5
Small signs for Test N-5	1050	1050	1050	1050
Large signs for Test N-5	336	336	336	336
Mailboxes for Test N-5	121	121	121	121
Construction barricades for Test N-5	504	504	504	504

Table 5-13 Requirements for Exposures to Roadside Objects in Test N-5

The number of trial exposures for each type of object (retroreflectors or debris) is the number of each type of object on the course multiplied by the number of passes through the course.

5.7.5.7 Data Reporting and Analysis

Data reported must demonstrate the validity of the test run. The reported measurements and analysis must demonstrate the following:

- The road geometry and prop locations met the requirements for the test.
- The SV speed was within the required limits for the horizontal curvature and superelevation of the curve from the time it came within 200 m of the first prop until it passed through 90 degrees of the curve.
- The SV lateral offset was within the specified limits from the time the SV came within 200 m of the first barrier until it passed through 90 degrees of the curve.

If an alert occurs, the data analysis and reporting must demonstrate whether one of the props caused it. If one of the props caused the alert, the data analysis and reporting must determine whether the alert occurred on the straight road, in the transition, or along the curve.

5.7.6 Test N-6: U-Turn With Sign

5.7.6.1 Test Overview and Purpose

This test is used to determine the sensitivity of an FCW system to signs found near U-Turn lanes in the median of a road. The signs are placed so that they are directly in front of the SV as it approaches the U-Turn, at a distance of 3 meters from the edge of the roadway. The SV approaches the U-turn at a high speed (80 kph), decelerates at the last moment, and then negotiates the turn.

The U-Turn should have a curvature consistent with a design speed between 20 and 50 kph. The SV approaches the U-Turn at 80 kph, brakes at 0.5g to reach the design speed just before entering the U-Turn, and then negotiates the turn.

5.7.6.2 Track and Prop Setup

Roadway Geometry and Conditions

Select a track that includes a straight segment leading into a very tight curve. The curve should represent a U-turn through a median between 12 m and 15 m wide, corresponding to a U-turn for passenger cars, busses, and medium semi-trailers in a divided road with 2 lanes in each direction (see AASHTO Figure IX-69, see References). There should be a curb on the outer edge of the U-turn curve.

Survey the road to determine the actual minimum radius of curvature and superelevation of the curve. The actual minimum radius of curvature in the turn will determine the speed at which the SV is driven around the curve. Determine the design speed for the measured combination of minimum radius of curvature and superelevation.

Signs

Place a 36" by 12"one-way sign on the outside of the curve so that it is directly ahead of the vehicle as it travels the straight part of the track. Place the sign perpendicular to the straight section of the track 1m away from the curb.

The design and location of the sign must be documented. Document the devices and techniques used to measure the locations of the sign relative to the roadway.

5.7.6.3 Environmental Conditions Requirements

Use standard conditions per Section 5.3.3.2.

5.7.6.4 Instrumentation Requirements

As the SV travels the "testing distance", instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV speed.
- Lateral position of the SV relative to the lane in road coordinates.
- SV brake pedal application (the pedal cannot be applied during testing, since this may disable the alerts for some FCW systems).

5.7.6.5 *Driving Instructions*

Begin at a location so that 80 km/h can reach before you are within 200 m of the U-turn. Accelerate to the required speed. Align the car so that it is in the center of the lane. Hold the speed steady within ±2 km/h and keep the center of the car within ±0.5 m of the center of the lane. At the last moment, brake at a comfortable-hard rate (tentatively set at 0.5g ±0.05g) to make the widest turn possible while staying on the track, and come to a stop after completing the turn.

Note whether any alerts are generated by the FCW system.

5.7.6.6 *Test Repetitions*

The following table indicates an estimated number for exposure to the U-turn scenario and during a typical day of driving and the resulting number of exposures that should be used in the tests.

	U-Turns
Average Exposure per Day	2
Number of Exposures for Test N-6	42

5.7.6.7 *Data Reporting and Analysis*

As the SV travels toward and through the turn, instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV speed and deceleration rate.
- Lateral position of the SV relative to the lane in road coordinates.
- SV brake pedal application. The pedal can be applied only once during the test and, once applied, must be held steady until the vehicle comes to a stop.

5.7.7 Test N-7: Slow Cars in Adjacent Lane at a Curve (Wet Pavement)

5.7.7.1 *Test Overview and Purpose*

This test determines the sensitivity of an FCW system to slower moving traffic in adjacent lanes. The test is difficult because, before the SV enters the curve, the slower vehicles in the adjacent lane are already directly ahead of the SV. The wet pavement makes it more difficult for some systems to properly handle this situation.

The countermeasure should not produce alerts as the SV approaches and then passes the traffic in the adjacent lane.

5.7.7.2 Track and Prop Setup

Roadway Geometry and Conditions

Select a track that is at least two lanes wide and that includes a straight segment that transitions to a curve. The curve should have a curvature and superelevation consistent with the AASHTO Policy on Geometric Design of Highways and Streets. The preferred radius of curvature in the curve is the 15th percentile for curves on public roads. Current engineering judgment suggests this radius of curvature should be appropriate for a design speed of 50 km/h to 70 km/h. According to AASHTO guidelines, this corresponds to radius of curvature values from 100 m (for 50 kph with 4% superelevation) to a curvature of 2000 m (for 70 kph with no superelevation). For additional details on the relationship between design speed, superelevation, and radius of curvature, see Tables III-7 to III-11 of the AASHTO Policy on Geometric Design of Highways and Streets (1994).

There should be a straight segment leading into the curve that is at least 200 m long. The straight segment should have a crown, curvature, and superelevation consistent with a straight, flat road.

The road surface should be wet. The standard lane marking condition – "good quality painted lane markings" – should be used (see Definitions section).

Survey the road to determine the actual minimum radius of curvature and superelevation of the curve. The actual minimum radius of curvature in the turn will determine the speed at which the SV is driven around the curve. Determine the design speed for the measured combination of minimum radius of curvature and superelevation.

Traffic

Several midsize passenger vehicles should be used.

5.7.7.3 Environmental Conditions Requirements

Use standard conditions per Section 5.3.3.2.

5.7.7.4 Instrumentation Requirements

As the SV travels toward and through the curve, instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV and POV speeds.
- Lateral position of the SV relative to the POVs, in road coordinates
- Heading angle of the SV relative to the road.
- SV brake pedal application (the pedal cannot be applied during testing, since this may disable the alerts for some FCW systems).

5.7.7.5 Driving Instructions

Drive a row of POVs around the track at half the design speed of the curve. Hold the speed within ±2 km/h of this speed. Maintain a lateral position within ±0.5 m of the center of the outer of the two lanes. Maintain a headway time of 1.5 s ±0.1 s between the POVs.

Drive the SV at the design speed for the inner lane of the curve. Maintain a lateral position within ±0.5 m of the center of the inner of the two lanes. The distances between the POVs and SV should be timed so that the SV approaches the curve while the POVs are on the part of the curve that is directly ahead of the straight part of the track.

The speeds and lateral positions of the POVs and SV should be maintained until the SV passes the POVs. Note whether any alerts are generated by the FCW system as it passes the slower traffic.

5.7.7.6 Test Repetitions

The following table indicates an estimated distribution of exposures to slow moving cars in adjacent lanes during a typical day of driving and the resulting number of exposures that should be used in the tests. If the test is run with a line of POVs then the number of exposures is calculated by multiplying the number of runs past the line of POVs by the number of POVs in the line.

Distance from Alert Zone (meters)	0.0-0.5	0.5-1.0	1.0-1.5
Average Exposure per Day	9	9	9
Number of Exposures for Test N-7	189	189	189

Table 5-14 Requirements for Exposure to Slow Cars in Adjacent Lane, Test N-7

5.7.7.7 Data Reporting and Analysis

Data reported must demonstrate the validity of the test run. The reported measurements and analysis must demonstrate the following:

- The road geometry met the requirements for the test.
- The POVs maintained the required speed, lateral, and longitudinal positions.
- The SV speed and lateral position was within the required limits from the time it came within 200 m of the curve until it passed the leading POV.

If an alert occurs the data analysis and reporting must demonstrate whether it was caused by the slower moving vehicles and which one caused it.

5.7.8 Test N-8: Trucks in Both Adjacent Lanes

5.7.8.1 Test Overview and Purpose

This test is used to determine the sensitivity of an FCW system to slower traffic that is at the same distance in both adjacent lanes. The test is difficult because the adjacent vehicles may be mistakenly interpreted as one vehicle directly ahead of the SV.

The countermeasure should not produce alerts as the SV approaches and then passes between the traffic in the adjacent lanes.

5.7.8.2 Track and Prop Setup

Roadway Geometry and Conditions

Select a flat, straight, track that is at least three lanes wide and 0.5 km long. The horizontal curvature, vertical curvature, superelevation, and crown of the track should meet the definition of a straight, flat road.

Principal other vehicles

The POVs should be two large trucks (Section 5.3.1.2 characterizes large trucks).

5.7.8.3 Environmental Conditions Requirements

Use standard conditions per Section 5.3.3.2.

5.7.8.4 Instrumentation Requirements

As the SV travels toward and passes between the trucks, the instrumentation must support a 95% confidence level that the following variables remain within their allowed values (as specified in the Driving Instructions):

- SV and POV speeds
- Lateral position of the SV relative to the POVs, in road coordinates
- Heading angle of the SV relative to the road
- SV brake pedal application (the pedal cannot be applied during testing, since this may disable the alerts for some FCW systems).

5.7.8.5 Driving Instructions

Drive the trucks at 60 km/h so that they are aligned with the center of the lanes adjacent to the lane the SV will use. Maintain the lateral positions within ±0.5 m of the center of each lane. Maintain the speeds so that they are within ±2 km/h of 60 km/h and within ±1 km/h of each other. Maintain the longitudinal positions of the trucks so their rear ends are within 0.5 m of each other.

Begin with the SV at least 200 m behind the trucks traveling at 120 km/h. Align the center of the SV with the center of the center lane. Maintain the lateral position of the SV within ±0.5 m of the center of its lane. Maintain the speed of the SV within ±2 km/h of 120 km/h as it approaches and then passes between the trucks.

Note whether any alerts are generated by the FCW system as it passes the slower traffic.

5.7.8.6 Test Repetitions

The following table indicates an estimated distribution of exposures to the scenario during a typical day of driving and the resulting number of exposures that should be used in the tests.

Distance from Alert Zone (Meters)	0.0-0.5	0.5-1.0	1.0-1.5
Average Exposure per Day	1	1	1
Number of Exposures for Test N-8	21	21	21

Table 5-15 Requirements for Exposure to Trucks in Adjacent Lanes, Test N-8

5.7.8.7 *Data Reporting and Analysis*

Data reported must demonstrate the validity of the test run. The reported measurements and analysis must demonstrate the following:

- The road geometry met the requirements for the test.
- The POVs maintained the required speed, lateral, and longitudinal positions.
- The SV speed and lateral position was within the required limits, from the time it came within 200 m of the POVs until it passed between them.

If an alert occurs, the data analysis and reporting must demonstrate whether it was caused by the slower moving vehicles.

5.7.9 Test N-9: Slow Cars in Adjacent Lane at a Curve (Poor Lane Markings)

5.7.9.1 *Test Overview and Purpose*

This test is used to determine the sensitivity of an FCW system to slower moving traffic in adjacent lanes. The test is difficult because, before the SV enters the curve, the slower vehicles in the adjacent lane are already directly ahead of the SV. The poor quality lane markings make it more difficult for some systems to properly handle this situation. This test is identical to Test N-7 except that (1) the pavement should be dry for this test, and (2) “poor quality painted lane markings” should be used (as described in the Definitions section). All other requirements and instructions are the same as Test N-7. Note that good quality lane markings can be made into poor quality lane markings (as defined in this chapter) by obscuring the lane markings, for example, by putting sand onto the surfaces.

5.7.9.2 *Test Repetitions*

The following table indicates an estimated distribution of exposures to the scenario during a typical day of driving and the resulting number of exposures that should be used in the tests.

Distance from Alert Zone (meters)	0.0-0.5	0.5-1.0	1.0-1.5
Average Exposure per Day	3	3	3
Number of Exposures for Test N-9	63	63	63

Table 5-16 Requirements for Exposure to Roadside Objects, Test N-9

5.8 Requirements Coverage Analysis

The purpose of the objective test methodology is to create a set of vehicle-level tests that evaluate whether or not a FCW system complies with the minimum functional requirements of Chapter 4. The only driver-vehicle interface requirements addressed by these tests involve crash alert onset timing (as stated in Sections 5.1 and 5.3). This section presents a chart that shows that all other requirements are all addressed by the proposed tests procedures.

Down the left column of Table 5-17 on the following page are the indices of the minimum functional and performance requirements that are taken from the requirements summary of Chapter 4, Section 7. Across the top of the table are the test numbers. The shaded boxes indicate which test procedures address each requirement. The driver-vehicle interface requirements not addressed in these tests are Requirements 1 and Requirements 3 through 12. These are not included on the chart.

The table shows that the test procedures address all of the intended functional requirements.

5.9 Summary

This chapter presents a set of objective test procedures that describe vehicle-level testing activities to evaluate the compliance of a FCW countermeasure with the minimum functional requirements developed in Chapter 4. Seventeen crash alert tests and nine out-of-path nuisances alert tests are described. The chapter reviews instrumentation requirements, track and prop set-up instructions, driving maneuver requirements, and data recording requirements. A coverage analysis shows the mapping from individual tests to the functional requirements in Chapter 4.

This test methodology is designed to provide repeatable countermeasure evaluations, and the sensitivity of results to the test site (proving ground) is minimized in the design. Test execution is estimated to require two to four weeks, not including initial prop fabrication, set-up, and surveying of test sites. Possible users of the tests may include vehicle manufacturers, countermeasure suppliers, government organizations, and independent institutions.

The following chapter, Chapter 6, covers the data analysis required to evaluate test data, as well as requirements for reporting on the tests. Chapter 7 describes an extensive set of activities undertaken to evaluate and validate the test methodology. This exercise resulted in changes to some important test design parameters and requirements.

Table 5-17 Functional Requirements and Associated Tests

Rquire- ment	C-, Crash Alert Test number																	N-, Nuisance Alert Test number								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1	2	3	4	5	6	7	8	9
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CHAPTER 6

DATA ANALYSIS AND REPORTING REQUIREMENTS FOR THE OBJECTIVE TEST METHODOLOGY

TABLE OF CONTENTS

6 DATA ANALYSIS AND REPORTING REQUIREMENTS FOR THE OBJECTIVE TEST METHODOLOGY

6.1 Introduction

A set of objective test procedures was proposed in Chapter 5 to evaluate the compliance of a Forward Collision Warning (FCW) system with the minimum functional requirements from Chapter 4. The vehicle-level test procedures include a detailed description of data collection requirements to support this testing. In this chapter, a set of requirements for data analysis is presented to support the test procedures. This analysis results in a pass/fail outcome for the FCW system.

6.2 Approach to Evaluating Countermeasure Performance

Section 6.2.1 summarizes key FCW system functional requirements in the context of evaluating test data. Section 6.2.2 describes the approach to using the outcomes of individual test trials to assess whether the countermeasure passes or fails the testing.

6.2.1 Minimal Functional Requirements

A set of minimum functional requirements for forward collision warning (FCW) systems are developed in Chapter 4. These requirements and corresponding tests may be partitioned into four groups:

- Driver-vehicle interface issues (How and when should an alert be presented to a driver?)
- Required crash alerts (When must an alert occur?)
- Out-of-path nuisance alerts (Alerts should not be triggered by objects outside the vehicle's path)
- In-path nuisance alerts (Alerts should not be triggered by vehicles in the Alert Zone unless the relative longitudinal motion would be considered alarming by drivers)

Driver-vehicle interface requirements include alert onset timing, alert modality, and other driver interface issues. The alert onset timing requirements are tested in the crash alert tests. Other driver-vehicle interface issues are not part of the test procedures. See Chapter 5, Section 2 for further discussion of the rationale for this approach.

The remainder of this section reviews the FCW system requirements associated with crash alerts, out-of-path nuisances, and in-path nuisances, from the perspective of using test measurements to assess a countermeasure's compliance with the functional requirements.

6.2.2 Evaluating Countermeasure Performance Using Test Results

A countermeasure passes the entire set of objective tests only if it passes each of three evaluation segments – crash alert tests, out-of-path nuisance alert tests, and in-path nuisance alert tests. If the results of one or more of these segments are not satisfactory, the countermeasure fails the entire set of tests.

Testing consists of executing several trials of each test scenario. For each individual test trial, the result is a pass/fail for one or more of the three evaluation segments. For crash alert test trials, the results are pass/fail for crash alerts (not too late/ too late) and for in-path nuisance alerts (not too early/ too early). For out-of-path nuisance alert test trials, the result is pass/fail for out-of-path alerts.

The following subsections describe briefly how each of the three segments use results of individual test trials to determine pass/fail outcomes. Obtaining results for a single test trial is discussed later, in Section 6.3 (crash alert tests) and Section 6.4 (out-of-path nuisance alert tests), and is also covered in each test procedure description (Chapter 5).

6.2.2.1 Pass/Fail Criteria for Crash Alert Test Segment

The crash alert test portion of the test procedures presents the countermeasure with 17 situations that should produce alerts in accordance with minimum functional requirements.

Successful countermeasure performance in the crash alert test portion requires that, for each of the five trials performed for each of the seventeen test scenarios, the onset of the crash alert should never be late. If the crash alert onset is late for one trial, fifteen more trials of that test must be run with no incident of late crash alerts, or the countermeasure fails the entire crash alert segment of the testing. If the crash alert onset is late for two trials, thirty more trials are required with no late crash alerts, and so forth.

These requirements are proposed because it is assumed that drivers will expect the FCW system will provide them with adequate braking distance (for good traction conditions).

Data collected during crash alert testing is also used for in-path nuisance alert evaluation, which is discussed next.

6.2.2.2 Pass/Fail Criteria for In-Path Nuisance Alert Segment

The data from all crash alert test trials is used to evaluate compliance with the in-path nuisance alert requirements.

In-path nuisance alerts are crash alerts that are triggered by vehicles inside the Alert Zone and that occur in situations drivers do not consider alarming. A suggested requirement from Chapter 4 on the frequency of in-path nuisance alerts is: less than one in-path nuisance alert per “week.” (That is, for a driving duration and exposure to traffic patterns representative of an “average” U.S. driver during a week).

The results of testing must be mapped to the requirement “fewer than one alert per week” in some manner. If the expected exposure to each test scenario during the theoretical representative driving week was known, then the number of in-path nuisances observed during testing could be scaled to give an expected in-path nuisance rate. This could then be compared to the requirement of less than one alert per week.

Unfortunately, the expected exposure to crash alert test scenarios is presently unknown. Instead, an estimate of the proper scaling and threshold parameters is shown later (Section 6.3.1.2). The result has the same form as the ideal method of mapping -- the occurrences of in-path nuisances are weighted by test scenarios and summed together. If the sum is less than a threshold, the system passes the in-path nuisance segment of testing. If not, it fails the in-path nuisance evaluation, and hence, the entire set of tests.

6.2.2.3 Pass/Fail Criteria for Out-of-Path Nuisance Alert Testing Segment

The out-of-path nuisance alert test procedures present the countermeasure with a set of situations representative of commonly occurring driving experiences in which objects or vehicles outside the Alert Zone may trigger out-of-path nuisance alerts.

Chapter 4 states that a very small number of out-of-path nuisance alerts are allowed. The requirement in the chapter is: less than one out-of-path nuisance alert per “week” (that is, for a driving pattern and duration equal to the average driving of a U.S. driver during a week), under representative conditions. Horowitz (1986) estimates the average U.S. driver covers 201 miles per week.

Mapping of the out-of-path nuisance alert test trial, results to the requirement “fewer than one alert per week” is done. Compared with the in-path nuisance evaluation, however, two steps toward better mapping have been made. First, the number of repetitions necessary to establish confidence has been estimated based on a pilot experimental study by CAMP (Appendix E). Second, the out-of-path objects are placed at various lateral distances from the Alert Zone to create a distribution of events. These distributions are described in Section 6.4.1.3 (also see Chapter 5).

With this mapping approach, a confidence of satisfactory performance for out-of-path nuisance alerts requires the system to produce no more than three crash alerts when the FCW equipped vehicle is exposed to three times the number of exposures expected in a week.

6.3 Crash Alert Tests – Data Analysis and Reporting

Chapter 5 describes 17 crash alert test scenarios. These are each repeated five times, and possibly more (see Chapter 5, Crash alert test repetition requirements).

This section describes general data reporting and analysis requirements, such as calibration issues and data processing issues that apply across most (if not all) crash alert tests. Next, each of the crash alert tests is addressed and any additional data reporting or analysis requirements are given.

6.3.1 Data Analysis and Reporting – General Requirements

Some data reporting and analysis requirements apply across many crash alert tests. This includes generic issues such as calibration requirements as well as detailed requirements on data reporting and analyses that apply across tests. Section 6.3.1.1 below describes general requirements for documenting "test validity," that is, reporting data and calculations to show test trials meet the specifications given in the procedures of Chapter 5. That section also levies requirements for documenting test execution. The third subsection below, Section 6.3.1.2, describes general requirements for reporting countermeasure performance metrics for individual crash alert test trials.

For each crash alert test, additional requirements appear later in Section 6.3.2.

6.3.1.1 Test Validity Analysis

Test validity analysis refers to the measurements and computations necessary to show that a test trial is valid, i.e., meets the requirements described in Chapter 5.

Calibration Documentation

Users of the test procedures should document compliance with all accuracy requirements given in the detailed test procedures of Chapter 5. Those requirements address the accuracy values of significant measurements, estimates, and controlled variables. The documentation of test results should describe calibrations and computations needed to show that the requirements are satisfied.

The list of uncertainties that need to be quantified will depend on the specific implementation of the test procedures.

Environmental Conditions Documentation

For each crash alert test, Chapter 5 specifies allowable values of various parameters describing ambient conditions. The user of the test procedures is responsible for gathering necessary measurements to verify that these conditions are met during the running of each trial. Documentation of these conditions for each test trial is required.

Vehicles, Props, and Test Site Documentation

Information on the vehicles and props involved in testing, as well as information on the test site itself, should be documented for each test design. Here some necessary information is listed and described.

Test Site – Requirements for the test site are given for each test in Chapter 5. The requirements are given in terms of a set of independent variables, which are defined in the Definitions section of that chapter. To show that the testing sites comply with these requirements, the user should describe the methods of measuring or determining the values of appropriate test site parameters. The user should also show that the resulting accuracy values support the determination that the test site characteristics are acceptable.

The following variables should be reported for each test site. The detailed procedures in Chapter 5 provide requirements for the ranges for each variable.

- Test site location
- Horizontal curvature
- Vertical curvature
- Descriptions of the type of lane markings present at the test site and the quality of the lane markings
- Lane width and lane width variation
- Roadway unevenness and superelevation parameters

Test Execution Documentation

Parameters Describing Vehicle Motions – Crash alert tests involve scripted maneuvers that are designed to trigger crash alerts in SVs equipped with countermeasure systems that satisfy the minimal functional requirements. For each crash alert test, Chapter 5 defines the maneuver, in part by describing allowable bounds on significant kinematics quantities, such as speeds, range, lateral position, and so forth. The required documentation associated with these specified motions is now described.

For any variable describing SV and/or POV motion for which Chapter 5 provides allowable bounds, there should be documentation that the measurements indicate that the bounds are satisfied. For each variable, three items should be included:

- The maximum deviation of the variable from the specification,
- The uncertainty associated with the measurement and/or estimation of the variable.
- Analysis that shows the variable was kept within the bounds given in Chapter 5 with a 95% confidence level.

For instance, if the SV speed is specified to be a constant 26.8 m/sec, with an allowable tolerance on either side of 0.67 m/sec, the documentation should report the maximum deviation from 26.8 m/sec, the estimated uncertainty in measuring SV speed (with justification), and a demonstration that the maximum deviation was less than 0.67 m/sec, with 95% probability.

Braking or Evasive Maneuvers – For each test run, one of the following questions must be answered in the positive, and documented, in order for the trial to apply:

- Does the required crash alert occur before the brake switch is triggered on the SV? or
- Does the range from the SV to the primary POV fall to less than 90% of the minimum range allowed for the onset of the crash alert before the brake switch is triggered on the SV (and before any other evasive action is taken by the driver of the SV)?

It is important to continue the driving maneuvers until one of the two situations above are attained, since countermeasures may use a variety of clues to help infer driver intentions.

6.3.1.2 Countermeasure Performance Analysis

Metrics to Report for Crash Alert Tests

For individual crash alert trials, the following items should be reported. In each case, the method of measurement and estimation should be documented.

- Estimated range from the SV to the POV at the time of alert onset.
- Estimated minimum required range at onset of alert. (See Chapter 4, Section 2 or Appendix B for instructions on computing this variable.)
- Difference between the range at alert onset and the minimum required warning range.
- Uncertainty in this difference.
- Estimated maximum allowed range at alert onset (to evaluate in-path nuisance alert events). See Chapter 4, Section 2 or Appendix B for discussion of this variable.
- Difference between the maximum allowed warning range and the actual range at onset of alert.
- Uncertainty in this difference.

It is also important to know the lateral position of the POV when the crash alerts are first presented to the driver, so that the compliance of the alerts with requirements can be determined. The following items should be reported:

- Estimated lateral distance between the nearest points on the POV and the SV, when the alert begins. Lateral distance is the difference in lateral positions, and lateral positions are measured with respect to the travel lane. Along with the quantities in the previous subsection, the lateral distance helps to determine whether an alert is required, allowed, or not allowed (Chapter 4, Section 3).
- Uncertainty in the above value (including effects of possible errors in knowing when the alert occurred, etc.).

Pass/Fail for Individual Crash Alert Test Trials

The metrics above should be used to locate the POV at the time of alert onset, and therefore allow the user to determine whether the crash alert onset met the requirements of Chapter 4. (The figure in Chapter 4, Section 3 illustrate a method of classifying a crash alert based on the POV location at the time of alert onset.) If the alert begins while the POV is in the “allowed” region of the figure in Chapter 4 (Region 4), the countermeasure passes the test trial. For all other results, the countermeasure fails the test trial.

Crash Alert Test C-11 may be passed another way. The test involves a SV approaching a stopped POV in poor visibility conditions. As described, a countermeasure passes this test if either the alert occurs at appropriate ranges or the countermeasure indicates to the driver that it cannot operate to its full function in the visibility conditions.

Pass/Fail Criteria for Individual In-Path Nuisance Alert Trials

Crash alert test trial results are examined, using the metrics above, to locate the POV at the time of alert onset and determine whether a crash alert onset is considered to be “too early,” that is, a in-path nuisance alert. The “too early” cutoff is described in Chapter 4, Section 2. Appendix B gives detailed instructions to compute the cutoff. If the alert is an in-path nuisance alert, this is included in a weighted sum of such instances, as described in the following subsection. If the weighted sum exceeds a threshold value, the FCW system fails the in-path nuisance alert segment of testing, and therefore fails overall.

The following subsection develops the weights and thresholds used to combine results of individual test trials to decide whether the FCW system passes this segment of testing evaluation.

Pass/Fail for the In-Path Nuisance Alert Segment Using Individual Test Trial Results

This section describes the details of combining results of in-path nuisance alert occurrences seen during testing to determine whether the countermeasure passes or fails the in-path nuisance segment. Section 6.2.2.2 explains that the approach described here uses a preliminary estimate of the exposure to situations similar to the crash alert test. Thus in-path nuisance alerts seen during testing can be “mapped” to expected rates during a hypothetical average drive.

There are 17 crash alert tests described in Chapter 5. For each trial, there is no distinction made between alerts that are very early and alerts that are slightly early. For the i^{th} crash alert test, let p_i denote the proportion of trials in which the crash alert is considered to be an in-path nuisance. Let w_i be a scalar weighting associated with the i^{th} test. Let the weighted sum of in-path nuisance occurrences in all tests be a metric of the countermeasure’s performance in the in-path nuisance segment of the tests. The countermeasure is considered to pass if the weighted sum does not exceed a threshold T_{IPNA}:

If $\sum_i w_i p_i \le T_{IPNA}$, the countermeasure passes in-path nuisance segment.

The choices of weights and threshold are now described. Ideally, weights assigned to the crash alert tests would be based on the relative exposure of drivers to the different test situations. In the absence of comprehensive data on driver braking behavior, weights are chosen by estimating the relative exposures of drivers to the testing situations. This is done using engineering judgment and the logic that follows. Weights are assigned to the crash alert tests based on (1) initial closing speeds, (2) POV braking severity, (3) presence or absence of lateral maneuvering. Weights do not consider roadway geometry and POV type since these parameters affect sensing and sensory interpretation performance, and in-path nuisance alerts involve alert timing.

To begin, a weight is assigned to each test based on the closing speed at the beginning of the test. Initial closing speeds vary from 0 to 100 kph. Weights are chosen to decrease as closing speeds increase; this is based on an assumption that the most common closing speed is zero, and as closing speeds increase, the probability that a driver is exposed to the closing speed decreases. The following table shows relative weights assigned to ranges of initial closing speeds.

Initial Closing Speed (kph)	Weight Assigned
0 – 25	100
26-50	50
51-75	20
76-100	10

Second, the weights are scaled by POV braking intensities, again based on an engineering sense of relative exposure to lead vehicle deceleration levels. The following scaling factors are used:

POV Braking Level	Scaling Factor
0.0 to –0.1g	1
-0.11g to –0.30g	0.30
-0.31g to –0.50g	0.05

Third, the weights are reduced for tests with lateral maneuvers, based on the simple assumption that crash alerts are more likely to happen when neither vehicle is changing lanes.

Lateral Maneuver Occurs?	Scaling Factor
No lateral maneuvers	1.0
SV lane change	0.3
POV cut-in	0.3

Table 6-1 shows the resulting weights to use for each test scenario.

Given the proportion of tests in which the crash alert tests produced an in-path nuisance alert, the system's performance is compared to a threshold, T_{IPNA}' as described earlier. The threshold is chosen here as follows. Assume, based only on engineering judgment, that "representative driving" for the U.S. (201 miles, Horiwitz) involves 10 incidents per week in which a driver approaches a situation in which a crash alert may be triggered. The requirements of Chapter 4 propose that in-path nuisance alerts should not occur more than once per week, for the week of "representative driving." Thus, given the normalized weighting of the tests shown in the table below, only one tenth of these incidences can be allowed to produce an in-path nuisance alert. Therefore the threshold is chosen to be 1/10, or $T_{IPNA} = 0.10$.

The choice of threshold, as well as the weightings, would be improved through the use of real-world data, such as that collected in the ICC Field Operational Tests (see References). The data might be used to better infer exposures to the scenarios represented by the crash alert tests, as well as provide a basis for a better estimate of how often drivers approach the "too early" bound of the crash alert onset requirements of Chapter 4.

Table 6-1 Weighting the Results Of Crash Alert Tests To Evaluate In-Path Nuisance Alerts

Test	Test Name	Scale Factor for Initial Closing Speed	Scale Factor for POV Braking	Scale Factor for Lateral Maneuvers	Total Test Weight	Normal-ized Weight
C-1	100 kph to POV stopped in travel lane	10	1	1	10	0.0266
C-2	80 kph to POV at 16 kph	20	1	1	20	0.0532
C-3	100 kph to POV braking moderately hard from 100 kph	100	0.05	1	5	0.0133
C-4	100 kph to POV stopped under overhead sign	10	1	1	10	0.0266
C-5	100 kph to slowed or stopped motorcycle	10	1	1	10	0.0266
C-6	SV to POV stopped in transition to curve	20	1	1	20	0.0532
C-7	SV to POV stopped in a curve	10	1	1	10	0.0266
C-8	SV to slower POV, in tight curve	50	1	1	50	0.1330
C-9	POV at 67 kph cuts in front of 100 kph SV	50	1	0.3	15	0.0399
C-10	SV at 72 kph changes lanes and encounters parked POV	20	1	0.3	6	0.0160
C-11	100 kph to stopped POV, with fog.	10	1	1	10	0.0266
C-12	POV brakes while SV tailgates at 100 kph.	100	0.3	1	30	0.0798
C-13	100 kph to 32 kph motorcycle between two trucks	20	1	1	20	0.0532
C-14	100 kph to 32 kph motorcycle behind a truck	20	1	1	20	0.0532
C-15	100 kph to 32 kph Truck	20	1	1	20	0.0532
C-16	SV to POV stopped in transition to curve (poor lane markings)	20	1	1	20	0.0532
C-17	24 kph SV to stopped POV	100	1	1	100	0.2660
				Sums:	376	1.00

6.3.2 Data Analysis and Reporting for Specific Crash Alert Tests

Unless otherwise specified, the quantities specified above in Section 6.3.1 should all be documented. Some tests require additional measurement and reporting; this section describes these unique requirements.

Refer to Chapter 5 for descriptions of the test procedures and objectives for these tests.

6.3.2.1 Test C-1: 100 kph to POV Stopped in Travel Lane

Additional Requirements to Demonstrate Test Validity

Stationary POV Location and Orientation – This test involves a stationary POV. The user is responsible for demonstrating that the POV location and orientation meets the requirement given in Chapter 5, under Crash Alert Test General Requirements.

Countermeasure Performance Evaluation

Only those requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.2 Test C-2: 80 kph to POV at 16 kph

Additional Requirements to Demonstrate Test Validity

None.

Countermeasure Performance Evaluation

Only those requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.3 Test C-3: 100 kph to POV Braking Moderately Hard From 100 kph

Additional Requirements to Demonstrate Test Validity

None.

Countermeasure Performance Evaluation

Only those requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.4 Test C-4: 100 kph to POV Stopped Under Overhead Sign

Additional Requirements to Demonstrate Test Validity

Overhead Sign – The overhead sign should be constructed and hung as defined in Chapter 5 (see in the Nuisance Alert sections); documentation should provide support for a statement that the overhead sign meets specifications.

Stationary POV Location and Orientation – This test involves a stationary POV. The user is responsible for demonstrating that the POV location and orientation meets the requirement given in Chapter 5, under Crash Alert Test General Requirements.

Countermeasure Performance Evaluation

Only those requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.5 Test C-5: 100 kph to Slowed or Stopped Motorcycle

Additional Requirements to Demonstrate Test Validity

Motorcycle -- The motorcycle should be as defined in Chapter 5.

Stationary POV Location and Orientation – This test involves a stationary POV. The user is responsible for demonstrating that the POV location and orientation meets the requirement given in Chapter 5, under Crash Alert Test General Requirements.

Countermeasure Performance Evaluation

Only those requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.6 Test C-6: SV to POV Parked in Transition to a Curve

Additional Requirements to Demonstrate Test Validity

Longitudinal Location of Vehicles – The longitudinal position of each vehicle should be recorded. Document the method used to locate the transition from the straight road segment to the curve.

Wet Pavement – Document whether the pavement is wet due to rain or artificial wetting of the road.

Countermeasure Performance Evaluation

Only those requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.7 Test C-7: SV to POV Parked on a Curve, No Lane Markings

Additional Requirements to Demonstrate Test Validity

Stationary POV Location and Orientation – This test involves a stationary POV. The user is responsible for demonstrating that the POV location and orientation meets the requirement given in Chapter 5, under Crash Alert Test General Requirements.

No Lane Markings – The user should document that the test is executed on a roadway that meets the requirement of a site with “no lane markings.” (See Chapter 5, Definitions.)

Countermeasure Performance Evaluation

Only those requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.8 Test C-8: SV to Slower-Moving POV, in Tight Curve

Additional Requirements to Demonstrate Test Validity

None.

Countermeasure Performance Evaluation

Only those requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.9 Test C-9: POV at 67 kph Cuts in Front of 100 kph SV

Additional Requirements to Demonstrate Test Validity

None.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.10 Test C-10: SV at 72 kph Changes Lanes and Encounters Parked POV

Additional Requirements to Demonstrate Test Validity

Stationary POV Location and Orientation – This test involves a stationary POV. The user is responsible for demonstrating that the POV location and orientation meets the requirement given in Chapter 5, under Crash alert Test General Requirements.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.11 Test C-11: 100 kph to Stopped POV, With Fog

Additional Requirements to Demonstrate Test Validity

Stationary POV Location and Orientation – This test involves a stationary POV. The user is responsible for demonstrating that the POV location and orientation meets the requirement given in Chapter 5, under Crash Alert Test General Requirements.

Visibility – The user is responsible for demonstrating that the atmospheric visibility at the time of the tests meets the requirements given for this test in Chapter 5.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test. In addition, the driver of the SV should observe whether the countermeasure indicates to the driver that the system cannot function at full functionality.

6.3.2.12 Test C-12: POV Brakes While SV Tailgates at 100 kph

Additional Requirements to Demonstrate Test Validity

None.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.13 Test C-13: Greater Size and Equal Distance

Additional Requirements to Demonstrate Test Validity

Motorcycle – The motorcycle should satisfy the requirements levied on motorcycles used in testing, per Chapter 5. Evidence that the motorcycle meets specifications should be included in the test documentation.

Trucks – Both trucks must meet the specifications of trucks to be used in the testing, per Chapter 5. Evidence that the trucks meet specifications should be included in the documentation.

Vehicle Longitudinal Locations – For this test Chapter 5 requires that the distance along the direction of travel between the rear of the three POVs should not exceed a specified amount. The testing organization should document support for an argument that the actual distances fall within that bound.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.14 Test C-14: Greater Size and Greater Distance

Additional Requirements to Demonstrate Test Validity

Motorcycle – The motorcycle should satisfy the requirements levied on motorcycles used in testing, per Chapter 5. Support that the motorcycle meets specifications should be included in the test documentation.

Trucks –Both trucks should meet the specifications of trucks to be used in the testing, per Chapter 5. Support that the trucks meet specifications should be included in the documentation.

Vehicle Longitudinal Locations – The maximum and minimum values for the estimated range between the motorcycle and the truck should be reported. Chapter 5 provides an allowable set of values that range can take on. The testing organization should document support for an argument that the actual range falls within that bound.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.15 Test C-15: 100 kph to 32 kph Truck

Additional Requirements to Demonstrate Test Validity

Truck – The truck should meet the specifications on trucks to be used in the testing, per Chapter 5. Support that the truck meets specifications should be included in test documentation.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.16 Test C-16: SV to POV Parked in Transition to a Curve, Poor Quality Painted Lane Markings

Additional Requirements to Demonstrate Test Validity

Longitudinal Location of Vehicles – The longitudinal position of each vehicle should be recorded. Document the method used to locate the transition from the straight road segment to the curve.

Painted Lane Markings of Poor Quality – The user should document the method used to determine whether the test roadway meets the requirements of a roadway with poor quality lane markings. Appropriate measurements and computations should be recorded and documented.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.3.2.17 Test C-17: 24 kph to Stopped POV

Additional Requirements to Demonstrate Test Validity

Stationary POV Location and Orientation – This test involves a stationary POV. The user is responsible for demonstrating that the POV location and orientation meets the requirement given in Chapter 5, under Crash Alert Test General Requirements.

Countermeasure Performance Evaluation

Requirements that apply to all crash alert tests (Section 6.3.1.2) are needed for this test.

6.4 Out-of-Path Nuisance Tests – Data Analysis and Reporting

Out-of-path nuisance-alert tests are used to evaluate the countermeasure's compliance to the limits on alerts caused by objects that are not in the Alert Zone. Chapter 5 described nine out-of-path nuisance-alert tests. The data analysis and reporting requirements described here include documentation to show that each test was run properly and documentation and analysis to demonstrate that the number of alerts were within the required limits. Some of the data analysis and reporting requirements apply to all of the tests while others are test specific. Section 6.4.1 covers the requirements that apply to all of the out-of-path nuisance-alert tests.

6.4.1 Data Analysis and Reporting – General Requirements

6.4.1.1 Test Validity Analysis

Calibration Documentation

Users of the test procedures must show that the quantities listed below meet the specifications given Chapter 5. Documentation should include the calibration procedures used, calibration results, and methods used to estimate the uncertainty for each of the following measurements:

- Uncertainty of lateral and longitudinal position of each stationary prop.
- Uncertainty of SV lateral position relative to each stationary prop as the SV drives through the test scene.
- Uncertainty of the SV speed as the SV drives through the test scene.
- Uncertainty of lateral position of moving POVs relative to the SV while the SV drives through the test scene.
- Uncertainty in the time of any alerts that are generated.

Principal Other Vehicles Documentation

Chapter 5 includes requirements for the types of vehicles that are used as the POVs. The make and model of each vehicle should be documented. Any options or configuration alternatives that could enhance or degrade the ability of a FCW system to sense the vehicles should be documented.

Documentation of Props

Chapter 5 includes requirements for the props that are used during the testing. The make and model of each purchased prop shall be recorded. The materials and dimensions of each prop that is constructed shall be documented. The vertical and horizontal displacement of props relative to the lanes of travel, including their position relative to any required vertical or horizontal curves, shall be documented.

Test Site Documentation

Chapter 5 includes requirements for the road surface characteristics. The road surface material and its roughness should be documented. The presence, location, and quality of painted lane markers or lane marking retroreflectors should also be documented. The individual tests also have limits on horizontal curvature, vertical curvature, and superelevation of the test track. The methods of measuring these characteristics and their values should be documented.

Test Execution

Each of the out-of-path nuisance-alert tests involves a scripted maneuver that causes the FCW equipped vehicle to approach an object that could, potentially, cause a nuisance alert. For each test scenario, Chapter 5 includes bounds on several significant kinematic quantities, such as speed and lateral position. The data analysis must include an analysis of the kinematic data, including an estimate of the measurement error, to demonstrate with a 0.95 level of significance that the maneuver was performed within the specified bounds.

6.4.1.2 Countermeasure Performance Analysis

The requirements in Chapter 4 state that a FCW system should produce less than one out-of-path nuisance alert per week when subjected to an average distribution of driving conditions. Chapter 5 describes how to expose a FCW system to representative scenarios that could generate out-of-path nuisance alerts. Each scenario is run multiple times using a distribution of distances between the objects and the Alert Zone. A system passes the out-of-path nuisance alert test segment if the sum of the number of alerts produced during all the repetitions is below a threshold.

This and the following sections explain how the required number of test repetitions and the distance distributions were derived. The number of repetitions is based upon three factors:

- An estimate of the daily or weekly exposure of a FCW system to each out-of-path nuisance alert scenario.

- An estimate of the distribution of distances of each type of object from the path of the SV.

- A statistical analysis of the number of trial exposures needed to have adequate confidence that a FCW system satisfies the limits for out-of-path nuisance alerts.

Several sources have been used to support estimates for the distribution of exposure rates. The research by Horowitz (1986) was used for the average miles driven in a week (201) and the average number of trips (27).

The values for exposure per day are based upon the findings of a pilot study performed by CAMP in suburban Detroit. Details of the study methods and results are included in Appendix D. The results of the pilot study are considered to be very preliminary, and therefore, the values presented here are likely to change when additional data becomes available.

The distribution of distances was derived by considering standard construction practices and using engineering judgements to translate these construction practices into reasonable distance distributions. The roadway configurations recommended by AASHTO were used to derive lane widths, roadway markings, as well as distances between the traveled roadway and guardrails or concrete barriers. The MUTCD was used for requirements on the locations of signs, raised retroreflectors, and portable construction barriers.

The statistical analysis for the required number of trials is presented in Section 6.4.1.3. Briefly, demonstration of satisfactory performance for alerts requires the system produce no more than three crash alerts when the FCW equipped vehicle is exposed to three times the number of exposures expected in a week.

$$3 \geq I \equiv \sum_{k=1}^{9} I_k \quad : k = \mathrm{N1} \quad \ldots \quad \mathrm{N9} \qquad \textbf{Equation 6-1}$$

where:

I_k is the number of crash alerts generated during the kth test,

I is the total number of alerts generated during the tests

6.4.1.3 Repetitions Needed for Out-of-Path Nuisance Alert Tests

The following analysis derives the requirements for the number of repetitions for each of the out-of-path nuisance alert tests.

The analysis is based upon the following considerations. First, it is assumed to be important that the number of trials is not excessive, so that the tests are feasible to execute. The introduction to Chapter 5 suggested that four weeks (for all tests) is a practical testing period, therefore two-weeks is assumed to be a practical duration for out-of-path nuisance alert testing.

Second, it is assumed that alerts are independent events. That is, whether an alert occurs in an encounter with one type of object is independent of the time since the last alert occurred or the presence of other objects.

Third, the SV is presented with essentially the same set of conditions several times. The trial repetitions provide the data required to estimate the likelihood that an alert will be produced under those conditions. Sets of trials are conducted for each of several distances between the objects and the Alert Zone. Successful performance in the out-of-path nuisance alert tests is based on the performance for all valid trials of the tests.

Suppose that the requirement for out-of-path nuisance alerts is that there be less than one alert in some time, T_i, of driving. Suppose that the number of encounters with sources of out-of-path nuisance alerts in time T_i is N_i. Then the requirement corresponds to a limit of $1/N_i$ on the probability that an encounter will cause a crash alert.

Terminology

A *scenario* is a general term that designates a combination of a driving pattern, a set of environmental conditions, and a set of objects or other vehicles that could cause a FCW system to produce an alert. Examples of scenarios include driving under a sign or approaching a stopped motorcycle.

An *incident*, or *encounter*, is a specific instance of a scenario. For example, each time a vehicle drives under a sign is one incident.

A *trial*, *run* or *repetition* is a specific experiment in which a vehicle equipped with a FCW system is driven toward one or more objects. A single trial can involve exposing the system to multiple incidents, such as driving past a row of slowly moving cars or over a series of road surface objects.

A *test* involves performing one or more repetitions of a scenario. The repetitions may be done so that each repetition is as similar as possible to the other repetitions. Alternatively, the repetitions may be done with one or more independent variables changed, such as when each run is closer than the previous to some roadside object.

A *sample* is the result of an experiment. An experiment may be one incident, one run, or one test.

A *sample space* is the set of all possible outcomes of an experiment. In statistics an *event* is a subset of the sample space. If an experiment involves exposing a FCW system to three incidents then sample space is the set of all possible combinations of outcomes from the three incidents and an event may be any outcome in which the FCW satisfies the minimum requirements all three times.

An *exposure rate* or *exposure frequency* is the number of times per day, week, or year that a FCW system is likely to experience a particular combination of conditions. For example, a system may be exposed to 500 roadside signs per week. Similarly, a system may be exposed to 20 cut-ins per week.

Trial Repetition Analysis

We want to conduct an experiment that will demonstrate whether or not a FCW system meets the requirements. So, an experiment will be conducted to estimate the frequencies of alerts.

Let p_i be the actual probability of an alert in one exposure. Let $q_i = 1 – p_i$ be the probability that an encounter will not generate an alert.

Let n be the number of trial exposures to sources of out-of-path nuisance alerts. Let x_i be the number of alerts generated in n exposures. The probability of x alerts in n exposures, p(x) is a binomial distribution. For large n the binomial distribution can be approximated by the Poisson distribution with mean $\mu = np$ and variance $\sigma^2 = np$. In addition, if $np \geq 5$ and $nq \geq 5$ then the binomial distribution can be approximated by a normal distribution with mean $\mu = np$ and variance $\sigma^2 = npq$. However, since we want to minimize the number of trials, we hope that we can use $n < 5N_i$, in which case the normal distribution approximation will not be very accurate.

The formula for the Poisson distribution is given by:

Equation 6-2

$$p(x) = \frac{\alpha^{x}}{x!} \times e^{-\alpha}$$

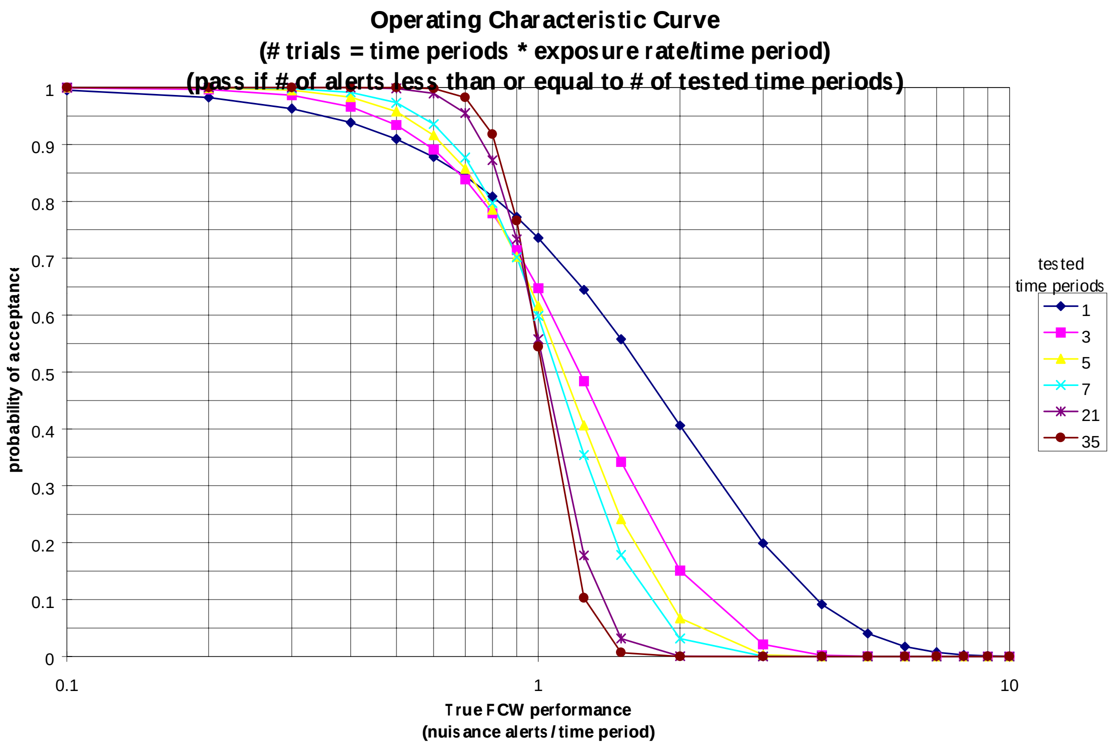
where

$$\alpha = np$$

We will use the maximum likelihood estimator of p_i which is x/n. The test specification will be that a system passes the test if $x_i/n \leq 1/N_i$.

The question is to determine a value for n that adequately discriminates between systems that meet the requirements and those that do not. Figure 6-1 shows a set of operating characteristic curves for different values of n.

Figure 6-1 Test Procedure Operating Characteristic Curves



The operating characteristic curves show the relationship between the true performance of a FCW system and its likelihood of passing the tests for different values of n. In Figure 6-1, the number of exposures is shown as an integer multiple of N_i. The tradeoff for selecting n involves examination of the likelihood that systems that exceed or do not meet the requirements by some amount will pass. It was decided to consider systems whose true nuisance alert rates are either half or twice the requirement. It is also informative to consider the likelihood of passing for a system whose performance is just at the limit for passing.

Consider a test set where $n=N_i$. Then a system whose p_i is $1/N_i$ will have a 74% chance of passing the test. Also, a system that has $p_i = 1/2N_i$ will have a 91% chance of passing and one that has $p_i =$

$2/N_i$ has a 40% chance of passing. As the number of exposures increases, the likelihood that a system will pass goes down if it has p_i exactly at the limit or twice the limit. Also, as the n increases the likelihood that a system that has a p_i that is half the limit will pass goes up. A value of $n=3N_i$ would provide less than a 15% chance that a system with twice the acceptable nuisance alerts would pass. Also, if $n=3N_i$, there is an 89% chance that a system with half the acceptable nuisance alerts will pass. This was judged by CAMP to provide adequate discrimination between systems that meet and those that do not meet the nuisance-alert rate requirements.

6.4.2 Data Analysis and Reporting For Specific Out-Of-Path Nuisance Alert Tests

6.4.2.1 Test N-1: Overhead Sign at Crest of Hill

This procedure test the sensitivity of a FCW system to objects commonly found over the traffic lanes of roads. The test covers the difficult condition wherein a crest curve causes the overhead object to appear directly ahead of the SV. The test is conducted using an overhead sign, which is used to representative both signs and bridges commonly found over urban and rural roads.

Additional Requirements to Demonstrate Test Validity

The test involves selecting a driving speed that corresponds to the design speed for the vertical curvature of the hill. The profile of the hill and the minimum rate of vertical curvature (in meters per % change in grade) must be reported.

The test should be run with the sign directly ahead of the SV and perpendicular to the grade of the hill before the crest. The report must include analysis of the orientation and position of the sign to show that the sign position and orientation satisfied this requirement when the tests were run.

If an alert occurs, verify that the sign caused the alert by comparing the measured distance between the SV and the sign with the reported distance to the object that caused the alert.

Countermeasure Performance Evaluation

The following table indicates a hypothetical distribution of heights that should be used in the tests. The total exposure is based upon the pilot study's estimated exposure of 12 overhead signs and 16 overhead traffic signals per day.

The height distribution is based upon an assumption that sign heights are evenly distributed between the minimum bridge height recommended by the AASHTO guidelines and a height 1 m above the minimum. The AASHTO guidelines recommend a minimum clearance for underpasses of 4.4 m with 5.0 m indicated as more desirable. In addition some roadways, including freeways and arterial systems, are parts of systems or routes for which a minimum vertical clearance of 4.9 m has been established for underpasses. The Manual on Uniform Traffic Control Devices (MUTCD) requires a minimum height of 17 feet (5.18m) unless the sign is placed on another lower structure such as a bridge.

The number of alerts generated during 21 days worth of exposure is I_{N-1} in equation 6-1.

Sign height above road (meters)	4.4-4.65	4.65-4.9	4.9-5.15	5.15-5.4
Average exposure per day	7	7	7	7

6.4.2.2 Test N-2: Road Surface Objects on Flat Roads

This test is used to determine the sensitivity of a FCW system to small objects that vehicles frequently drive over. The representative objects include lane-marking retro-reflectors, tire debris, beverage cans, and a piece of wood. The test is conducted on a straight section of track.

Additional Requirements to Demonstrate Test Validity

Report the manufacturer and model of the retroreflectors used in the test.

Report whether the vehicle passed over each of the types of road surface objects.

Countermeasure Performance Evaluation

When retroreflectors are used on rural roads, the AASHTO guidelines suggest that they be placed at intervals that are twice the interval for broken line segments. The recommendation is that broken line segments consist of 10' segments and 30' gaps. Therefore, when retroreflectors are present on rural roads the recommended spacing is one every 80' (24.4 m). Horowitz (1986) reported an average driving distance of 201 miles/week (323 km/week). However, typically only a fraction of the distance traveled would have raised retroreflectors as lane markings. The pilot study found no retroreflectors on the route traveled. To provide a meaningful test, The following table assumes that approximately 5% of the distance traveled would have raised retroreflectors.

The pilot study found no instances of debris in the through-traffic lanes of the route taken. To provide a meaningful test the frequency at which vehicles drive over debris such as beverage cans, pieces of wood, or pieces of tires is assumed to be less than once every other day (i.e., about once every 57 miles of travel).

The following table indicates a hypothetical distribution for exposure to road surface objects that should be used in the tests.

	Road Surface Retroreflectors	**Debris**
Average Exposure Per Day	100	0.5

The number of trial exposures for each type of object (retroreflectors or debris) is the number of each type of object on the course multiplied by the number of passes through the course.

The number of alerts generated during 21 days worth of exposure is I_{N-2} in equation 6-1.

6.4.2.3 Test N-3: Grating at Bottom of Hill

This test is used to determine the sensitivity of a FCW system to metal road surface objects, such as a grating, that vehicles frequently drive over. The test is conducted so that the visibility of the grating is increased by its location on a sag vertical curve.

Additional Requirements to Demonstrate Test Validity

Document the construction of the grating to demonstrate it meets the requirements set forth in Chapter 5.

Countermeasure Performance Evaluation

Although gratings and manhole covers are common, they are less commonly found in the center of a lane at the bottom of a hill. No such instances were found during the pilot study. The following table indicates a hypothetical distribution for the typical exposure of FCW systems, to gratings at the bottom of a hill.

	Grating at Bottom of Hill
Average Exposure per Day	1

The number of alerts generated during 21 days worth of exposure is I_{N-3} in equation 6-1.

6.4.2.4 Test N-4: Guardrails and Concrete Barriers

This test is used to determine the sensitivity of a FCW system to roadside barriers such as metal guardrails and concrete dividers.

Additional Requirements to Demonstrate Test Validity

Document the construction of the guardrails and Concrete Barriers to demonstrate that they conform to the requirements contained in Chapter 5.

Countermeasure Performance Evaluation

The following table indicates a hypothetical distribution for the typical exposure of FCW systems to guardrails and concrete barriers. The total exposure is based upon the pilot study, which suggests vehicles are exposed to 19 guardrails and 5 concrete barriers per day in the near vicinity to the lane they are traveling in.

The distribution of distances from the Alert Zone is based upon an assumption that the distribution of barriers from the edge of a lane is evenly distributed from the minimum recommended by the AASHTO guidelines to the maximum that is 4 meters from the edge of the lane. The AASHTO guidelines suggest that barriers on highways be placed no closer to the roadway than the recommended shoulder width. On local roads and streets barriers may be as close as 0.5 m from the roadway. The minimum shoulder width in the median of highways is 1.2m on four lane highways with a minimum of 3.0 m on six lane highways. For the right hand shoulder the recommended minimum shoulder width for the lowest volume roadways is 0.6 m with a preferred width of 1.2 to 2.4 m. For high-volume high-speed roadways the recommended minimum is 3.0 m with a preferred width of 3.6 m.

Distance of Object from Alert Zone (meters)	0.5-1.5	1.5-2.5	2.5 to 3.5	3.5 to 4.5
Guardrails (Typical Exposure per Day)	5	5	5	5
Concrete Barriers (Typical Exposure per Day)	1	1	1	1

The number of alerts generated during 21 days worth of exposure is $I_{N\text{-}4}$ in equation 6-1.

6.4.2.5 Test N-5: Roadside Objects by Straight and Curved Roads

This test is used to determine the sensitivity of a FCW system to common roadside objects. The representative objects include small and large signs, mailboxes, and construction barricades.

Additional Requirements to Demonstrate Test Validity

No Lane Markings – The user should document that the test is executed on a roadway that meets the requirement of a site with “no lane markings.” (See Chapter 5, Definitions, for a definition.)

Countermeasure Performance Evaluation

The following table indicates a hypothetical distribution for the typical exposure of FCW systems to roadside objects. The total exposure for each type of object is based upon the pilot study results.

The distributions of distances from the Alert Zone are based upon an assumption that sign locations are evenly distributed between the minimum distance from the roadway to a distance 2 m farther than the minimum. The MUTCD recommends that signs should not be closer than 6 feet (1.8 m) from the edge of the shoulder, or if no shoulder is present, no less than 12 feet (3.65 m) from the edge of the traveled way. In urban areas, where necessary, a clearance of 1 foot (0.3 m) from the curb face is permissible. The table takes into consideration that vehicles do not always travel in an outside lane and do not normally travel along the edge of a lane. In addition it is assumed, for lack of a better estimate, that there are an average of 8 small signs, 4 large signs, and 4 mailboxes per mile of travel. Based on Horowitz (1986) the average distance driven per day is 28.7 miles.

Part VI of the MUTCD includes recommended practices for the location of temporary barricades to divert traffic in road maintenance zones. The guidelines include recommended practices for shoulder tapers and tapers for shifting lanes. In general, there will not be a shoulder between temporary barriers and the traveled way. Therefore, the table assumes that the barriers will be on the edge of the traveled way. The recommended practice is to space the barriers so that the distance between them (in feet) does not exceed the speed (in mph) when used for a taper and should not exceed twice the speed when used for tangent channeling. The table assumes, for lack of a better estimate, that FCW equipped vehicles will pass an average of 0.5 km of road with construction barriers per day spaced at 40-ft intervals.

Distance of Object from Alert Zone (Meters)	0.5-1.5	1.5-2.5	2.5 to 3.5	3.5 to 4.5
Small signs	50	50	50	50
Large signs	16	16	16	16
Mailboxes	11	11	11	11
Construction barricades	24	24	24	24

The number of alerts generated during 21 days worth of exposure is I_{N-5} in equation 6-1.

6.4.2.6 Test N-6: U-Turn with Sign

This test is used to determine the sensitivity of a FCW system to signs found near U-turn lanes in the median of a road. The signs are placed so that they are directly in front of the SV as it approaches the U-turn, at a distance of 3 meters from the edge of the roadway. The SV approaches the U-turn at a high speed, decelerates at the last moment, and then negotiates the turn.

Additional Requirements to Demonstrate Test Validity

None.

Countermeasure Performance Evaluation

The following table suggests a hypothetical distribution for the typical exposure of FCW systems to this scenario. The total exposure is based upon the pilot study, which suggests that two U-turns per day.

	U-Turns
Average Exposure per Day	2

The number of alerts generated during 21 days worth of exposure is I_{N-6} in equation 6-1.

6.4.2.7 Test N-7: Slow Cars in Adjacent Lane at a Curve

This test is used to determine the sensitivity of a FCW system to slower moving traffic in adjacent lanes. The test is conducted where a curve puts slower traffic directly ahead of the SV as it approaches the curve.

Additional Requirements to Demonstrate Test Validity

The make and model of the slow cars must be recorded. If they are not the same as the standard vehicles then their optical or radar cross sections (whichever is appropriate for the sensing technology) should be demonstrated to be within 20% of the cross sections for the standard vehicle.

The test is to be executed on wet pavement. Report whether the pavement is wet due to rain or artificial wetting.

Countermeasure Performance Evaluation

No statistical data or guideline information was available to support a value for the total exposure to slow moving cars in adjacent lanes. The pilot test indicated a total exposure of 2 slow moving and 16 parked or stopped vehicles in adjacent lanes per day. To provide a more meaningful test the frequency which vehicles drive past slow moving cars was assumed to be 20. There are two tests for this scenario, one with wet pavement (with good lane markings) and one with poor quality lane markings (and dry pavement). For the purposes of these tests, the total exposure is divided with 75% on dry pavement and 25% on wet pavement.

The following table indicates a hypothetical distribution of the distances of cars in adjacent lanes from the Alert Zone. The table is based upon an assumption that the lateral distances between cars will be evenly distributed with an average equivalent to the distance if both vehicles were in the center of their lane and with a minimum of 0.5 m. Assuming an average lane width that is half way between the AASHTO minimum for low-volume low-speed streets, (3.0 m) and the recommended width for interstate highways (3.6m) and an average vehicle width of 2.1 m yields an average separation of 1.2 m. The values in the following table are adjusted to account for the distance that the Alert Zone extends beyond the side of the FCW equipped vehicle and rounded for convenience.

Distance from Alert Zone (meters)	0.0-0.5	0.5-1.0	1.0-1.5
Average Exposure per Day	9	9	9

The number of alerts generated during 21 days worth of exposure is $I_{N\text{-}7}$ in equation 6-1.

6.4.2.8 Test N-8: Trucks in Both Adjacent Lanes

This test is used to determine the sensitivity of a FCW system to slower traffic that is at the same distance in both adjacent lanes. The test determines whether adjacent vehicles may be mistakenly interpreted as one vehicle directly ahead of the SV.

Additional Requirements to Demonstrate Test Validity

The make and model of the trucks must be recorded. If they are not the same as the standard trucks then their optical or radar cross sections (whichever is appropriate for the sensing technology) should be demonstrated to be within 20% of the cross sections for the standard trucks.

Countermeasure Performance Evaluation

No statistical data or guideline information was available to support a value for the total exposure to situations where there are slow moving vehicles at the same distance in both adjacent lanes. The pilot study did not experience any events of this type. To provide a reasonable test, it was assumed that a typical driver would experience this scenario three times during an average day of driving (28.7 miles).

The following table indicates a hypothetical distribution of distances of cars in adjacent lanes from the Alert Zone. The distribution of distances is based upon the same logic as was used for the table in Section 6.4.2.7.

Distance from Alert Zone (meters)	0.0-0.5	0.5-1.0	1.0-1.5
Average Exposure per Day	1	1	1

The number of alerts generated during 21 days worth of exposure is I_{N-8} in equation 6-1.

6.4.2.9 Test N-9: Slow Cars in Adjacent Lane at a Curve, Poor Quality Painted Lane Markings

This new test is identical to N-7, except that this test is to be run on a dry roadway with poor quality painted lane markings.

Additional Requirements to Demonstrate Test Validity

The make and model of the slow cars must be recorded. If they are not the same as the standard vehicles then their optical or radar cross sections (whichever is appropriate for the sensing technology) should be demonstrated to be within 20% of the cross sections for the standard vehicle.

The test is to be executed at a test site with poor lane markings. Document all measurements and observations made that support the claim that the lane markings meet the requirements for such a test site.

Countermeasure Performance Evaluation

All remarks for Test N-7 apply here.

Distance from Alert Zone (meters)	0.0-0.5	0.5-1.0	1.0-1.5
Average Exposure per Day	3	3	3

The number of alerts generated during 21 days worth of exposure is I_{N-9} in equation 6-1.

6.5 Conclusions

This chapter specifies requirements for analysis and reporting of data collected during the execution of the objective tests. The outcome is a determination of whether or not a FCW system meets the set of minimum functional requirements developed in Chapter 4.

6.6 References

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CHAPTER 7

OBJECTIVE TEST METHODOLOGY EVALUATION

TABLE OF CONTENTS

List Of Figures

List Of Tables

7 FORWARD COLLISION WARNING SYSTEMS TEST PROCEDURES EVALUATION

7.1 Introduction

This chapter describes activities that focused on validating and improving the objective test methodology described in Chapters 6 and 7. The methodology includes twenty-six vehicle-level tests designed to evaluate the compliance of a FCW system with the set of minimum functional requirements developed in Chapter 4. There are several areas of the methodology that were evaluated.

The philosophy set forth when the test procedures for FCW systems were developed was that the tests should be executable by a variety of organizations and at a variety of existing track facilities. This required test specifications that would be interpreted the same way by different test engineers and that would accommodate the differences in the tracks and standard practices at different testing facilities. In addition, the tests were designed to be independent of the sensing technology used by the FCW system. In particular they need to be applicable to systems based upon millimeter wave radar, laser radar or video sensors. A major consideration was to devise tests that would produce consistent results when executed at different locations. Three sites were selected as representative of those accessible by the organizations that would execute the tests. These were the G.M. Milford Proving Ground near Milford, MI, the Ford Motor Company's Michigan Proving Ground near Romeo, MI, and the Transportation Research Center near East Liberty, Ohio.

The primary focus of the evaluation reported here is to provide an initial assessment as to whether the tests are practical to execute and provide a reasonable certainty that a FCW system which passes the tests actually satisfies the minimum functional requirements. Another concern addressed is whether the test results will be repeatable.

A major focus of the validation work was the execution of five key tests from among the twenty-six proposed. These tests were conducted using both a laser radar system and a microwave radar FCW system. The laser radar FCW system was installed on a vehicle instrumented to collect independent estimates of vehicle motion and position. The microwave radar system was installed on a different vehicle with identical instrumentation. The FCW systems were acquired from Mitsubishi Electronics of America (laser radar) and Eaton Vorad (microwave radar) solely for the purpose of validating the methodology. Performance evaluation of those specific systems was not the focus of the testing and no performance results are reported here.

Section 7.2 describes the process of selecting instrumentation for the vehicle testing activities. Section 7.3 presents the resulting testing setup. Section 7.4 describes the validation procedure and activities. This includes both the testing work and the work away from the track. The work reported here led to improvements in several test procedures presented in Chapter 5. The methodological approach and scope, however, remain intact.

7.2 Instrumentation Selection Process

Included in this section are discussions of measurements, props, test track facility requirements, challenges and a brief description of the process used to determine the instrumentation.

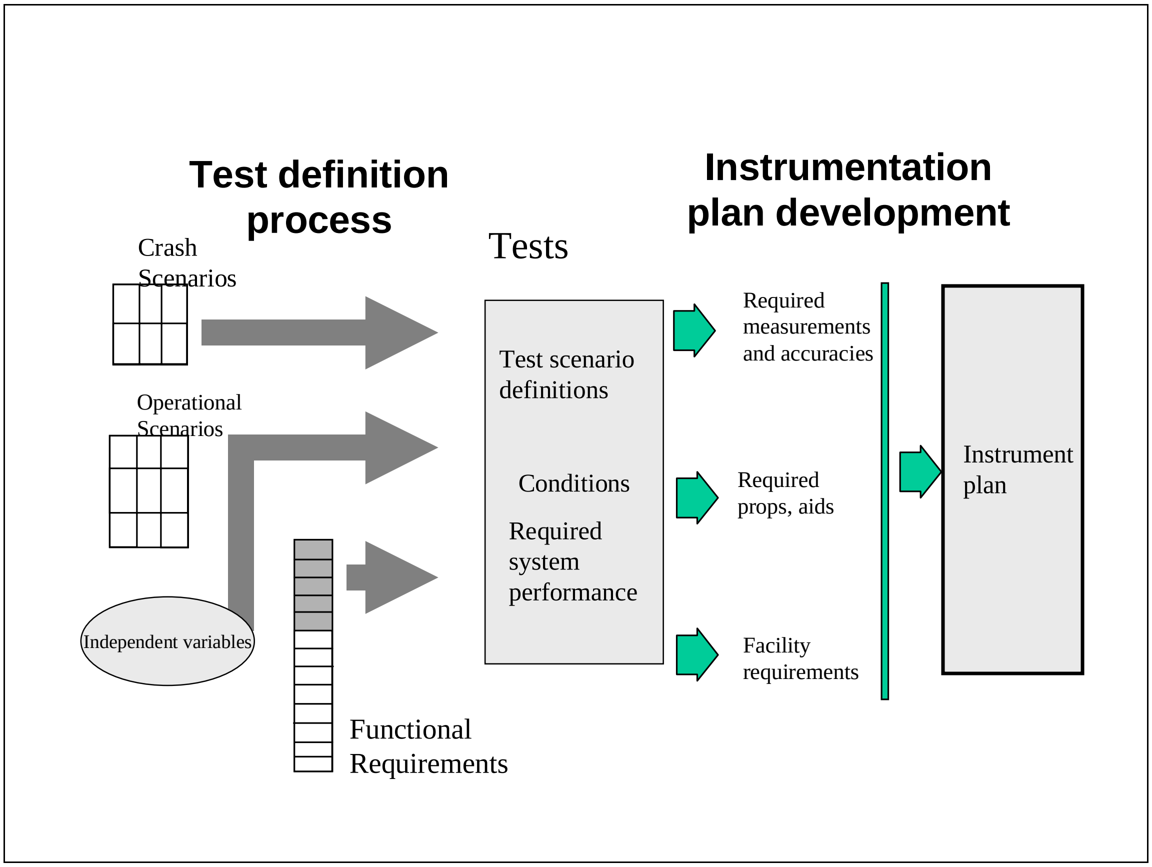


Figure 7-1 Instrumentation Plan Development Process

Figure 7.1 illustrates the process used to develop the tests and the list of instrumentation. The test procedures include variations of the Crash and Operational Scenarios. The variations are selected so that the ranges of values of each of the independent variables are represented adequately amongst the tests. The test definitions include the test scenario definitions, conditions that must be controlled when running the test, and the required system performance. These were then used to define the required measurements and accuracy's documented herein.

The purpose of conducting the tests is to evaluate the test procedures. The required measurements were selected so that it could be determined, first, whether a system passed the test, and second, that the test was conducted properly. This process required measurements of sufficient accuracy to both exercise the procedures (through evaluation of two FCWs) and to evaluate the procedures themselves. The test conditions, passing criteria, and background for each test were analyzed to determine the accuracy requirements for each measurement. Finally, alternative instrumentation approaches for each type of measurement were evaluated to determine which could satisfy the accuracy requirements. The resulting list of instrumentation used for the CAMP testing is provided in Appendix E.

7.2.1 Required Measurements and Accuracy

This section presents and justifies required measurements, accuracy, and data rates to support the testing. The abbreviation “SV” refers to the “subject vehicle,” the vehicle equipped with the FCW under test. The abbreviation “POV” refers to “principal-other-vehicle,” which includes any other vehicles in the immediate vicinity.

Figure 7-2 is a schematic of the onboard instrumentation on the test vehicles. Table 7-1 summarizes the required measurements and the corresponding accuracy and data rates. These results are developed in the remainder of the section, with supporting materials included in Appendix E.

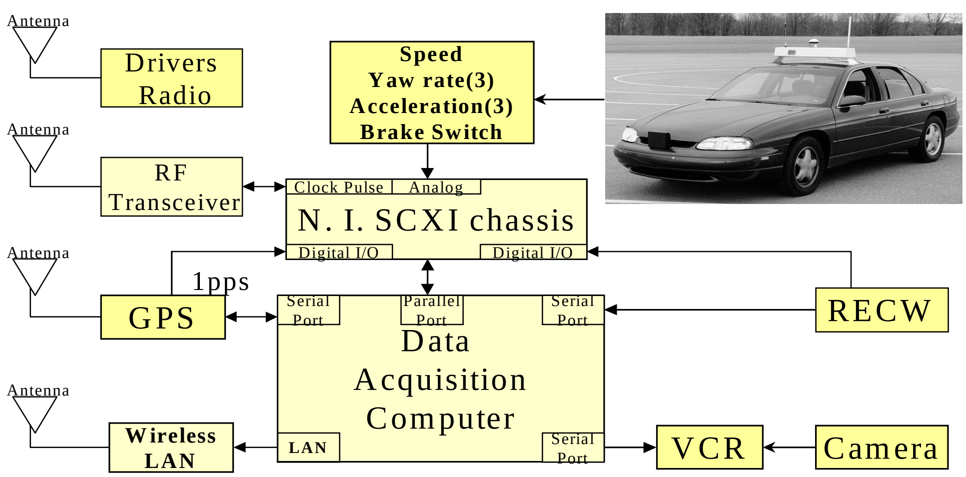


Figure 7-2 Block Diagram of In-Vehicle Instrumentation

Table 7-1 Summary of Required Measurement Accuracy and Data Rates

Measurement	Accuracy (3 sigma)	Onboard Data Rate Required	Supporting Section
Longitudinal position of SV, POVs, and clutter	6 cm	10 Hz	7.2.2
Longitudinal speed of SV and POVs	0.09m/s	10 Hz	7.2.2
Longitudinal acceleration of SV and POVs	0.10 m/s/s	10 Hz	7.2.2
Lateral position of clutter, stationary POVs and road	3 cm	NA	7.2.3
Lateral position of SV and moving POVs	10.5 cm	4 Hz	7.2.3
Yaw rate of SV and POV	1.8°/s	20 Hz	7.2.4
Visibility	10 m	NA	7.2.5
Brake pedal actuation time	0.10 sec	10 Hz	7.2.6
Roadway horizontal curvature (direction change)	1°	NA	7.2.7
Roadway elevation change (for super-elevation and vertical curvature)	5 mm/5m	NA	7.2.8

Note that Table 7-1shows requirements in terms of *absolute* positions or speeds, whereas the requirements addressed position and speed variables which are primarily *relative* quantities. The requirements in Chapter 4 define an “Alert Zone”, which is a zone stretching in front of the SV and following the shape of the road. Objects within this zone must trigger alerts under certain conditions (based on the range and range rate). Objects outside the Alert Zone should not trigger alerts. Therefore, when evaluating the performance of a FCW system, it is important to know whether objects or POVs are within the Alert Zone, as well as knowing the range and range rate to the object or POV. These are *relative* measurements, e.g., lateral position of a roadside object with respect to the SV.

During the process of developing measurement strategies, accuracy and instrumentation concepts, it became clear that the use of Differential Global Positioning System (DGPS) would best meet the combined set of requirements, including accuracy for these relative measurements, cost, flexibility during testing and testing design, availability, and schedule. Thus, Table 7-1 and the remainder of Section 7.2 are based on the approach of measuring motion with respect to an earth-fixed frame. Section 7.2.10 discusses the selection of a GPS approach and addresses the issues of choosing from among GPS solutions.

The following sections address the individual measurements listed in Table 7-1.

7.2.2 Longitudinal Position, Speed, and Acceleration

The requirements for measurement accuracy of longitudinal motion variables of the tes vehicles are driven by crash scenario testing. The crash scenario tests involve maneuvers designed to trigger crash alerts. The FCW is then evaluated based on the range at which the alert occurred. For tests in which an alert in the SV is expected or desired, the crash alert timing criterion in Chapter 4 describes a minimum range at which the alert must occur (Section 4.2.3.1). The minimum required range is a function of range rate and parameters of a model describing the driver's anticipated reaction time and braking level. The FCW meets the requirement as long as the alert occurs at a range that is equal to, or greater than, the minimum range given by the requirements in Chapter 4. The required minimum range for an alert may be as small as 2.2 meters or as great as 100 meters (these are, respectively, the minimum and maximum longitudinal extents of the Alert Zone suggested in Chapter 4).

Figure 7-3 shows an SV and a POV at the moment a FCW issues an alert. To evaluate whether a FCW system meets this requirement, the difference between the actual range at alert onset, *R*, and the minimum required range for the situation, R_{warn}, is computed. If $R \geq R_{warn}$, then the FCW passes the test trial. If, however, $R < R_{warn}$, then the FCW fails the test trial. Let ε_R denote the difference, $\varepsilon_R = R - R_{warn}$. This difference is the basic metric to be used in evaluating the FCW system's compliance with the minimum warning range requirement.

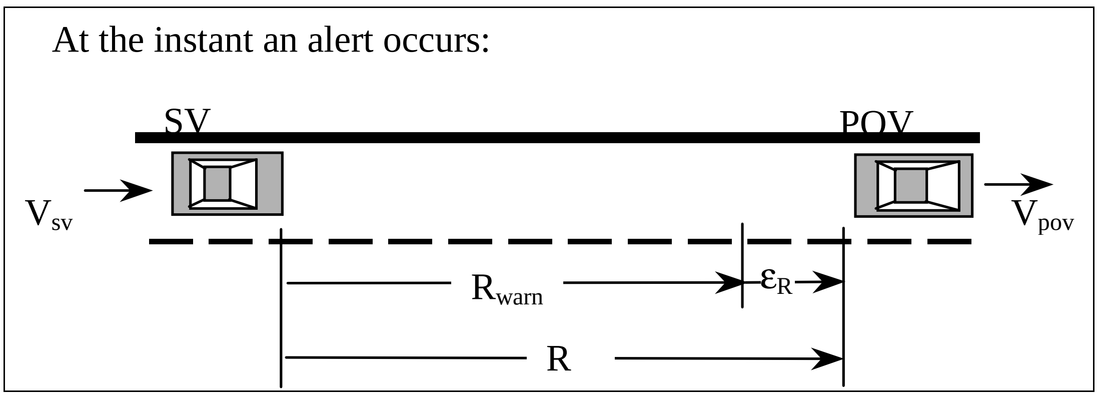


Figure 7-3 Comparing Actual Warning Range to the Minimum Required Warning Range

Measurement accuracy's should support the computation of the metric ε_R so that evaluation of the FCW system's warning range performance on a trial will be correct "almost always." When using data from an individual test trial to determine whether the FCW passed the trial, the following requirement is suggested:

The following 3-sigma requirement is levied: measurement error effects on the computation of the difference between the true range at the instant of alert and the minimum warning range cannot be greater than 5% of the minimum warning range, or 2.0 meters, whichever is greater.

Let $\hat{\varepsilon}_R$ denote the computed value of the metric, based on measurements. Then data from a test trial would be evaluated as follows:

If $\hat{\varepsilon}_R > max(0.05 * R_{warn}, 2.0m)$, then FCW passes trial (high confidence), If $\hat{\varepsilon}_R < max(-0.05 * R_{warn}, -2.0m)$, then FCW fails trial (high confidence), and

If $|\hat{\varepsilon}_R| \le max(0.05 * R_{warn}, 2.0m)$, then there may not be enough confidence to state that the FCW passed or failed the trial.

The "high confidence" is quite high – if the error in the metric is assumed to follow a normal distribution, for instance, the probability that the conclusion is correct is 99.7%.

The third condition above corresponds to cases in which the estimated range at alert time is quite close to the estimated minimum required range at alert time, and the effect of measurement uncertainties is large enough to call into question any conclusions. The frequency with which results fall into this region depends on both the measurement accuracy and the closeness of the FCW performances to the required warning ranges. By tightening measurement accuracy, this region of uncertainty can be shrunk but not eliminated.

There is a tradeoff, however, between tightening measurement requirements and keeping equipment cost and testing feasibility within practical ranges. Appendix E lists the equipment selected for validation testing of the test procedures; the equipment choices are largely driven by requirements of ground-truthing lateral positions during lateral maneuvers.. The boxed requirement above can be met with the equipment listed in Appendix E, *assuming that the minimum warning range is closing-speed dependent.* Testing occurred with a draft set of alert timing requirements that depended on closing speed. Appendix E, Section E.3 demonstrates that the boxed requirement above is satisfied for the draft set of timing requirements. The analysis in the appendix develops an analytical expression for the metric of warning range performance, then computes a 3-sigma value for the uncertainty in the metric, given instrument accuracy and data rates:

- Vehicle position, longitudinally: 0.06m, 3 sigma (SV, all POVs)
- Vehicle speed, longitudinally: 0.09m/s, 3 sigma (SV, all POVs)
- Longitudinal acceleration: 0.10 m/s^2, 3 sigma (SV, POV – only one vehicle brakes during testing at any one time)
- Time at which the alert occurred: 0.050 sec, 3 sigma

The analysis assumes upper bounds on the following test conditions and variables:

- Range rate < 33 m/sec (120kph),
- Relative acceleration between vehicles in the longitudinal direction, magnitude no greater than 0.3g,
- Time between onset of alert and collection of measurements of vehicle positions, speeds, and accelerations: <0.250 sec

The above requirements are also sufficient for tests with a stationary POV since the location of the POV can be surveyed to within a few centimeters. The above requirements on longitudinal motions are also more than adequate to provide measurements for documenting test execution, for purposes of investigating anomalies, proving “acceptable” execution of the tests, or for validating the test procedures

7.2.3 Moving SV and POV Lateral Positions

Most of the test scenarios require measurement of the lateral position of the SV. However there are two types of tests with much tighter requirements. These are (1) the tests that involve the SV driving by stationary objects that are just outside the Alert Zone, and (2) the tests that involve lateral maneuvers, either by the SV or the POV. Although the analysis shows that the lateral maneuvers have the tightest position measurement requirements, the development of both requirements are presented here for review.

The requirements state that the Alert Zone extends along the path of the road with a width that extends beyond the width of the SV on either side (maximum width of 3.6 meters). An alert should occur if a POV is in the Alert Zone and the longitudinal distance and relative velocity requirements are met. Furthermore, alerts should not occur due to objects that are outside the Alert Zone.

7.2.3.1 Lateral Position Relative to Stationary Objects

For scenarios with stationary objects that always remain outside of the Alert Zone, the procedures will require that the SV pass within some distance from the other object. There is an implicit lateral tolerance on how accurately the SV must be driven. The requirement is that the SV drive by the stationary objects so the Alert Zone stays between 0.0 m and 0.5 m lateral offset from the objects.

The measurements must be accurate enough to provide assurance that the actual path of the SV was within this 0.5 m band. However, the accuracy with which the SV can be driven has an impact on the accuracy requirements for the lateral position measurements (Figure 7.4).

For now we can assume that the position of the stationary objects can be determined much more accurately than the position of the moving SV. Surveying techniques that measure the position of stationary objects with a 3σ accuracy of 3 cm should be used.

Suppose that the SV can be driven so that the maximum lateral deviation from the desired path is 10 cm. To allow for the variation in the actual path and the uncertainty of the position measurements, the desired path is selected to put the Alert Zone 0.25 m from the stationary object. Then it is required that the 3 sigma measurement error be such that a vehicle that is 10 cm from the desired path should produce measurements that are inside the 0.0 m to 0.5 m limits. This would be accomplished if 3σ = 25 cm – 10 cm or 15 cm.

Then, for the stationary object tests, a 3σ lateral offset accuracy of 15 cm is required.

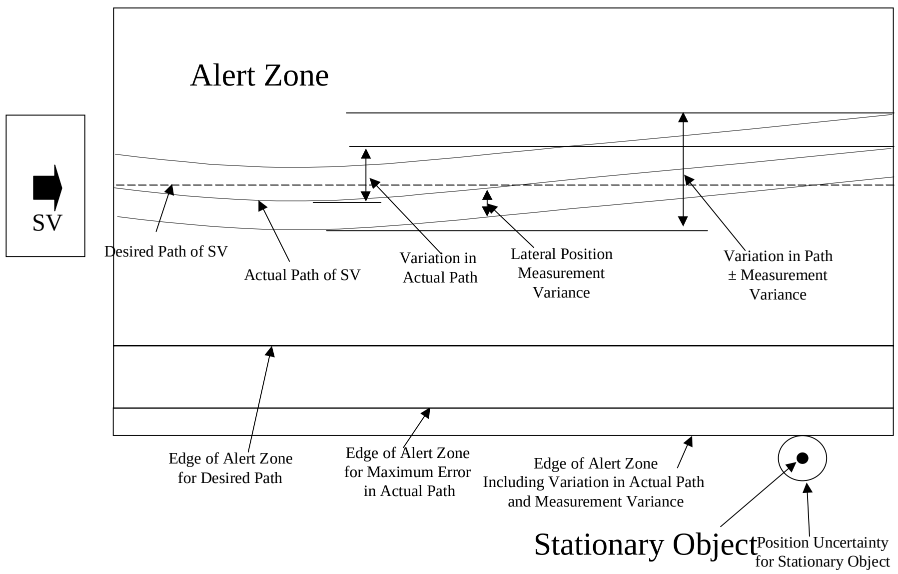


Figure 7-4 Tolerance Stackup for Lateral Position Measurements with Stationary Object Outside the Alert Zone

7.2.3.2 Lateral Position During Lateral Maneuvers

In section 4.3.1, the requirements state that the Alert Zone extends along the path of the road with a minimum width corresponding to the width of the vehicle and a maximum width that extends beyond either side of the SV to a maximum width of 3.6 meters. The requirements indicate an alert should occur no later than when the path of the SV or the POV are such that the POV crosses into the minimum width of the Alert Zone from the side (see Figure 4.6).

Considering the likely vehicle width, these requirement might allow a lateral tolerance of 0.5 m for when the alert must occur on a cut-in. In other words, an alert should not occur before a POV enters the outer limit for the Alert Zone from the side and it must occur before the side of the POV gets less than the inner limit of the Alert Zone, if the speed and distance conditions are met.

Next, engineering judgment suggests that the measurement uncertainty be less than 10% of the width of the tolerance zone. This will provide a high level of confidence that, when an alert occurs, it is certain whether the side of the POV was between the limits for the width of the Alert Zone. Then $\sigma = 0.1 \times 50$ cm = 5 cm. Therefore, the instrumentation must provide a lateral offset accuracy less than 5 cm. Since absolute position measurements from 2 vehicles will be required to achieve the lateral offset calculation, each must have an accuracy of 0.707 x 5 cm = 3.5 cm.

So, for lateral maneuvers, the required measurement accuracy for lateral position would be 3.5 cm for each vehicle.

7.2.4 Yaw Rate

Yaw rate is required to measure vehicle positions when GPS is not available and to improve position interpolation between GPS readings. The maximum yaw rate can be estimated by assuming a maximum turn rate with a lateral acceleration of 0.3g. Experts at Ford and GM have suggested that this is the highest comfortable value for most drivers. For a curvature, R, and speed, V, the lateral acceleration is V^2/R. The yaw rate, ω, is V/R=a/V.

The yaw rate accuracy requirement is derived from the need to know the lateral position of a vehicle relative to the road or another vehicle. The lateral position of the Alert Zone relative to the road depends on the lateral position of the SV. Consider the simple case where the vehicle is supposed to be going straight. If the actual lateral yaw rate of the SV is ω then the lateral offset, l, that occurs between samples is:

$$l = (V/\omega) \{ \cos\theta_o - \cos (\theta_o + \omega T) \} + l_o$$

Where T is the time between samples, θ_o is the initial yaw angle and l_o is the initial lateral offset. The sensitivity, s_ω, of the lateral offset estimate to errors in ω is:

$$s_\omega = dl/d\omega = - (V/\omega^2) \{ \cos\theta_o - \cos (\theta_o + \omega T) \} - (V/\omega) T \sin (\theta_o + \omega T)$$

The standard deviation in lateral position estimates, σ_l, that occurs between samples would be:

$$\sigma_l = |s_\omega| \sigma_\omega$$

$$\sigma_\omega = \sigma_l / |s_\omega| = \sigma_l / |- (V/\omega^2) \{ \cos\theta_o - \cos (\theta_o + \omega T) \} - (V/\omega) T \sin (\theta_o + \omega T)|$$

Assuming that T=0.25 sec, σ_l = 2 cm; that ω, and θ_o are zero; and that V is 110 kph then

$$\sigma_\omega \cong \sigma_l / (VT^2)$$

$$\sigma_\omega \cong 0.0105 \text{ rad/s} = 0.600°/\text{s}$$

So a yaw rate sensor with a 3σ accuracy of 1.8°/s would be adequate.

7.2.5 Visibility

Visibility measurements are required to provide repeatability for the low visibility tests. Fog, rain, or dust should be generated to simulate low visibility conditions. Instrumentation is required to measure visibility of approximately 200m. The requirements state that the systems must either operate normally or indicate that they cannot function properly under the current conditions. It seems reasonable that a 10% variation in the visibility conditions will still produce repeatable results. Therefore the visibility instrumentation must have an accuracy that is better than 10% at 200m visibility.

7.2.6 SV Brake Pedal Actuation Time

SV brake activation time is needed to determine whether a test driver suppressed an alert by applying the brake (perhaps in maneuvering for safety). The brakes are not to be applied, except for evasive maneuvers required after the desired test results have been collected. To ensure this is the case, a brake pedal switch is recommended. The 0.1-second accuracy will be adequate.

7.2.7 Roadway Horizontal Curvature

Roadway curvature measurements are required to determine the speeds at which test vehicles must be driven around curves. The AASHTO policy defines guidelines for the relationship between design speed, radius of curvature, and super-elevation. Tables III-7 to III-11 of the AASHTO Policy on Geometric Design of Highways and Streets indicate radius of curvature for various design speeds and super-elevation slopes.

The test procedures call for curves similar to a tight highway cloverleaf. They also specify limits on the curvature for tests intended for straight roads. The Federal Highway Administration Highway Performance Monitoring System (HPMS) database indicates that 85% of the curves on rural highways, freeways, and arteries have a curvature of less than 4.4°/100m. This corresponds to a radius of curvature of 1302 meters.

Although it might be argued that an 85^{th} percentile curve is adequate for testing of FCW systems, it was decided that tight cloverleaf curves are important for testing the number of nuisance alarms produced by a system. Observations on local highways indicate that a curve corresponding to a 40 kph design speed should be included in the test scenarios. The AASHTO guidelines suggest that the radius of curvature for a curve with a design speed of 40 kph with a 4% super-elevation should be no less than 60 meters.

Therefore the instrumentation should be able to measure radius of curvature between 60m and 1300m. For a small radius of curvature, the angle change over a fixed distance of road can be measured. For longer radii, the distance can be measured for which a 1° change in road direction occurs. In either case, the ability to measure distances up to 300 m to 1 cm and angles to 1° will provide adequate information to determine the design speed of a curve.

7.2.8 Roadway Super-Elevation on Curves and Vertical Curvature

Super-elevation measurements are required to determine the speeds at which test vehicles must be driven around curves. The AASHTO Policy on Geometric Design of Highways and Streets defines guidelines for the relationship between super-elevation, design speed, the radius of curvature, and side friction factor of a road. Tables III-7 to III-11 of the policy guidelines indicate super-elevation requirements to 0.1 % for design speed increments of 10 kph. Therefore, slope measurements with an accuracy of 0.1 percent will be needed to determine the design speed of a curve to within ±5 kph.

Vertical curvature measurements will also be required to determine the speed at which test vehicles must be driven at a sign at the top of a hill. The AASHTO policy defines guidelines for the relationship between vertical curvature (sag & crest curves) and design speeds. The vertical curvatures are expressed in meters per percent change in grade. To distinguish whether a vertical curve is for a design speed of 110 kph vs 120 kph, the measurements must be accurate enough to distinguish between roads with curvatures of 202 m/% and 151 m/%.

Since the test specifies a constant car speed, the curvature only needs to be measured often enough to know that the car was at the right speed about once a second. If the car is traveling 120 kph then the grade only needs to be measured at points separated by 0.5 to 1 second or approximately every 15 to 30 meters.

Another way to determine how often the grade needs to be measured is to assume it should be about 20% of the maximum length of the Alert Zone, or 20 m. Over 20m the slopes for hills designed for 110 kph and 120 kph would have a change of grade of 0.099% and 0.132% respectively. Putting this in terms of angles the difference in slopes that must be distinguished is between 0.0567 degrees and 0.0756 degrees, a difference of 0.0189 degrees.

The simplest way to measure the vertical radius of curvature would be to measure elevation relative to the top of the hill at various points along the road. If elevation is measured every 5 meters then the change in slope over 20 meters can be measured. Over 5 meters a slope measurement with an accuracy of 0.1% would require measuring the change in elevation to 5mm.

Therefore, equipment is required that can measure changes in elevation with an accuracy of 5 mm over distances of 5 meters and to measure distances of up to 20 meters between elevation measurement locations.

7.2.9 Sampling Rate for Onboard Data Acquisition Systems

The most pressing data rate requirement for the onboard acquisition system is driven by the need to measure vehicle-to-target lateral offsets during tests with lateral maneuvers, for instance, for a test with a POV cutting into the host SV's lane. Since the critical vehicle handling bandwidth will be less than 2 Hz, the required data rate is selected as ten times that bandwidth, or 20 Hz.

Appendix E develops the individual data rate requirements for each required measurement of Table 2.1. This demonstrates that the 20 Hz rate is sufficient.

7.2.10 Ground Truth

As part of the FCW test procedure validation, measurements were recorded to verify that the alerts occurred at the appropriate relative distance. The FCW systems could provide this information, but due to system delays and other limiting information, a separate independent method was needed. Several differential Global Positioning Systems were found to have the potential measurement and accuracy capability to meet the requirement.

For these instruments, the advertised DGPS accuracy is 3cm with baseline distances less than 10km to a base station. By placing a DGPS receiver on each moving vehicle and having a stationary reference base station, the position of the moving vehicles and stationary objects can be recorded during the test procedure.

7.2.10.1 DGPS Data Collected at a 4 hz Rate

The data output rate from a DGPS receiver depends on the type of receiver. If a dual frequency, real-time position measurement is used, then a 4 Hz output can be expected. For a single frequency with only data logging then a 20 Hz output can be expected.

For the best accuracy, it was decided to post-process the DGPS data. Post–processing eliminates errors from communication delays between base and mobile receivers. Commercial software was used to process the GPS information.

7.2.10.2 GPS Options

A comparison of three GPS receivers was made for the purpose of selecting a receiver that would meet the measurement accuracy requirements. All three are specified to be dual frequency, real-time kinematics, and high accuracy receivers. Each receiver was selected from a different manufacturer. They are Trimble model 7400Msi, Ashtech Z-12, NovAtel Millenium RT-2. The estimated cost shown in the table below is for four receivers that are needed to perform the testing.

	Trimble	Ashtech	NovAtel
Position Accuracy	3 cm	3 cm	2 cm
Data Rate	5 Hz	10 Hz	4 Hz
Velocity Accuracy			0.03 m/s
Est. Cost	$77,800	$80,700	$79,400

7.2.10.3 GPS Selection

All receivers selected for the comparison would have met the needs. The estimated costs are about the same. It appears that the selection of a DGPS receiver is not critical, but limited to dual frequency, real time kinematics for the best accuracy.

7.2.10.4 Required Supporting Measurement

Interference of GPS satellite signals by trees, bridges, and tunnels are a common problem. Other GPS users recommend that other vehicle state sensors be used to help bridge the gap when the satellite signals are not available for short periods of time. For this reason the following sensors were used in addition to the DGPS for ground truth metrics: accelerometers, ABS wheel speed sensors, and gyros for vehicle yaw, pitch, and roll rates.

7.2.10.5 Software Development

The integration of vehicle state information, DGPS, and radar information into one data file was a custom software job. Each device had its own unique format that was combined to a common data format. Synchronization of the data had to be addressed because some of the devices had different update rates.

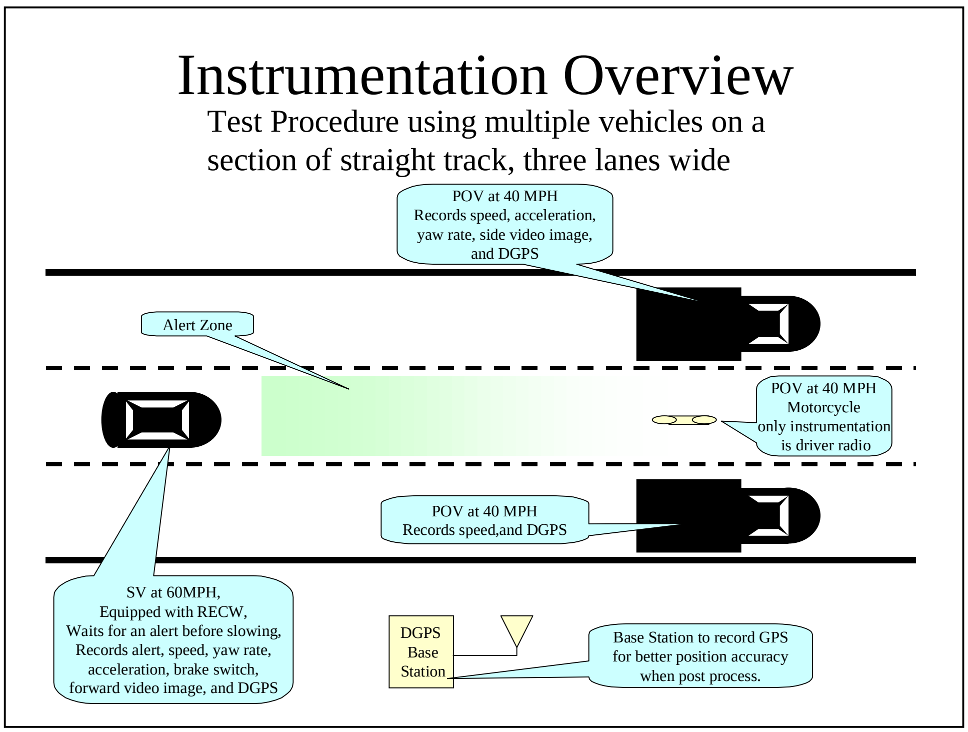


Figure 7-5 Use of Vehicle Instrumentation for a Complex Test

7.3 CAMP Testing Equipment/Instrumentation

The test procedures place requirements upon the type of information that must be collected and the accuracy of the measurements. Validating the test procedures imposed additional instrumentation requirements. The instrumentation was selected to meet these requirements. The data collection rates were selected by considering the vehicle dynamics limits.

Figure 5 illustrates how the vehicle instrumentation was used for a complex test scenario. Vehicle motion during dynamic testing was determined by vehicle speed, brake pedal switch, yaw-pitch-roll rates, acceleration in three axis, and relative position on a test track from DGPS. By knowing the precise vehicle motion and relative position during the testing, the motion of the Alert Zone was calculated. Evaluation of the data collected during the test procedure showed when objects moved into and/or out of the Alert Zone during the dynamic testing. The FCW systems provided real-time feed back to aid in performing the test procedures.

The photographs that follow illustrate how the equipment was installed into the test vehicles. Appendix E includes a list of equipment used and selected manufacturers' data sheets.

7.3.1 Basic Instrumentation

The data collected from the vehicles includes vehicle speed and brake pedal action. An accelerometer is installed to provide acceleration in three axes and rotation rates about the axes. This information is collected as analog inputs through a signal conditioning front-end to the data acquisition computer. The video recorder, Global Positioning System (GPS) receiver, and countermeasure device are interfaced to the computer through serial ports. When multiple cars are used for a test, the data acquisition computer establishes a network link to control the beginning and end of each test from one car. Communication with other drivers is through hand-held radios.

The data acquisition program was developed using National Instruments LabView software. When the data acquisition program is started, the operator in each vehicle identifies which vehicle the equipment was installed (SV, POV1, POV2). The operator in the SV uses that computer to control the computers in the other vehicles. The driver of the SV selects a data rate and controls the start and stop of data collection for the GPS receivers and all other instruments. A reference GPS site was used to collect data at the same time so correction can be made to the GPS data during post processing. The GPS site is referred to as the base station and is not shown here.

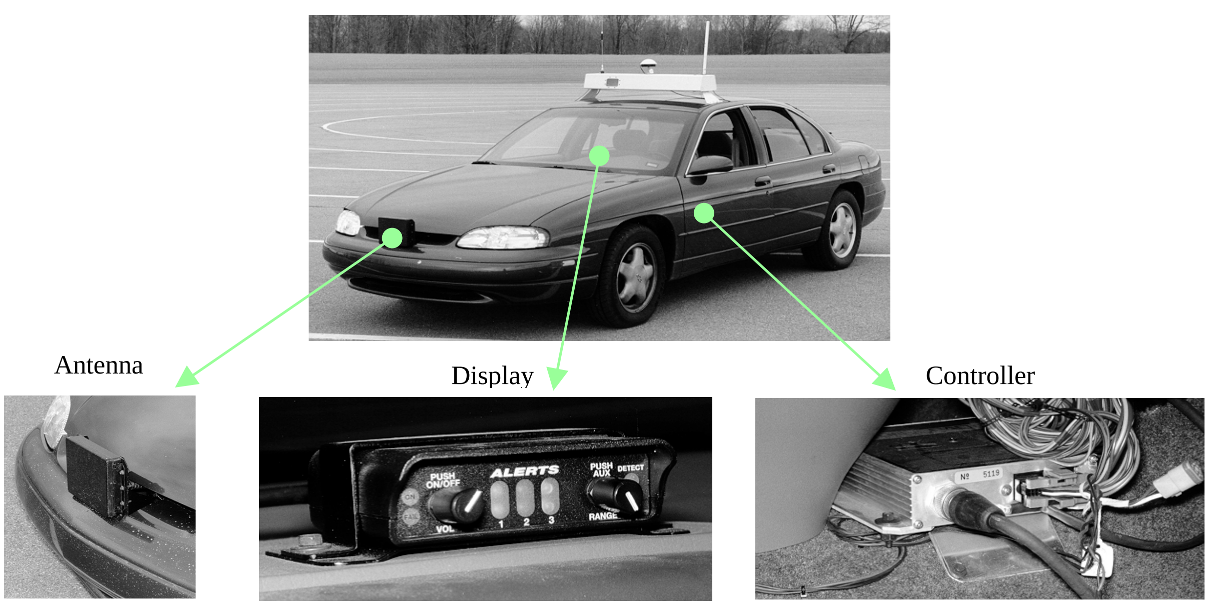
7.3.1.1 Photographs of Instrumented Vehicles

This photograph shows the three CAMP Test Cars. From left to right, they are the 1996 Mitsubishi Diamante 30RSE, and the two 1997 Chevrolet Lumina LTZs.

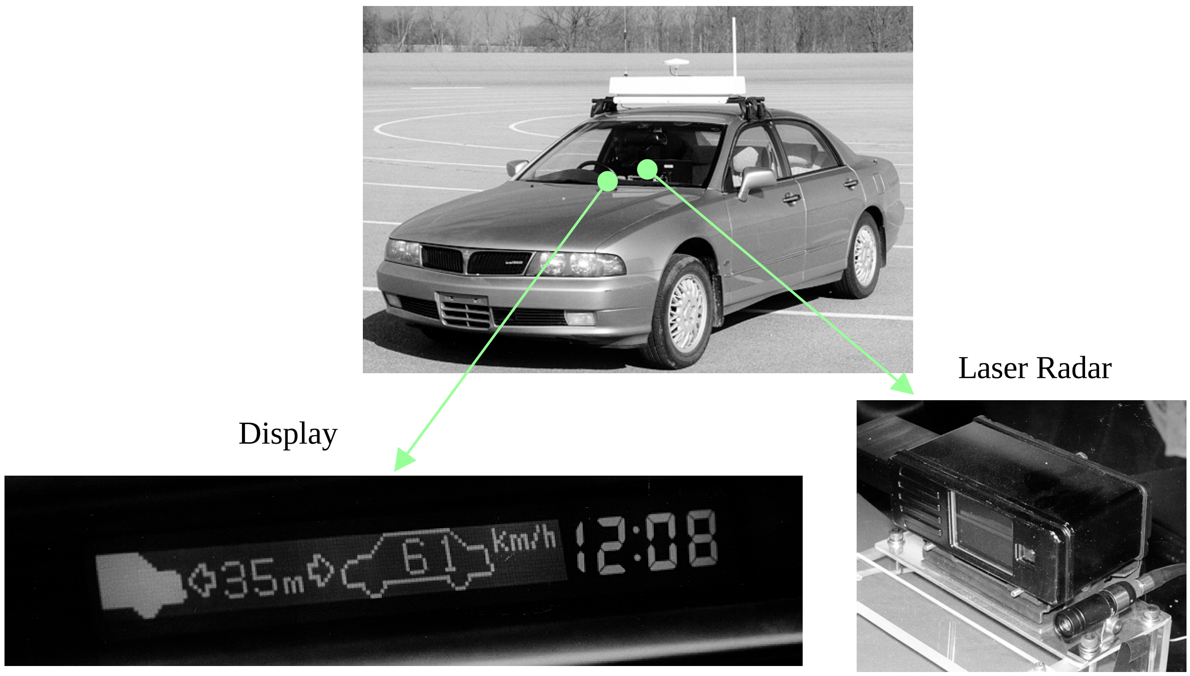
This photograph shows the two trucks and a motorcycle used for testing. These vehicles were rented for one week of testing.

7.3.1.2 Countermeasure Systems Installation

The Chevrolet Lumina LTZ was equipped with a microwave radar FCW system commercially available, the Eaton Vorad EVT-200. These photographs show where the equipment was installed. The display is on top of the instrument panel to the right of the driver. The controller is located under the instrument panel on the hump between the driver's and passenger's feet. The wires are on the passenger side of the vehicle to prevent interference with the driver's pedals.

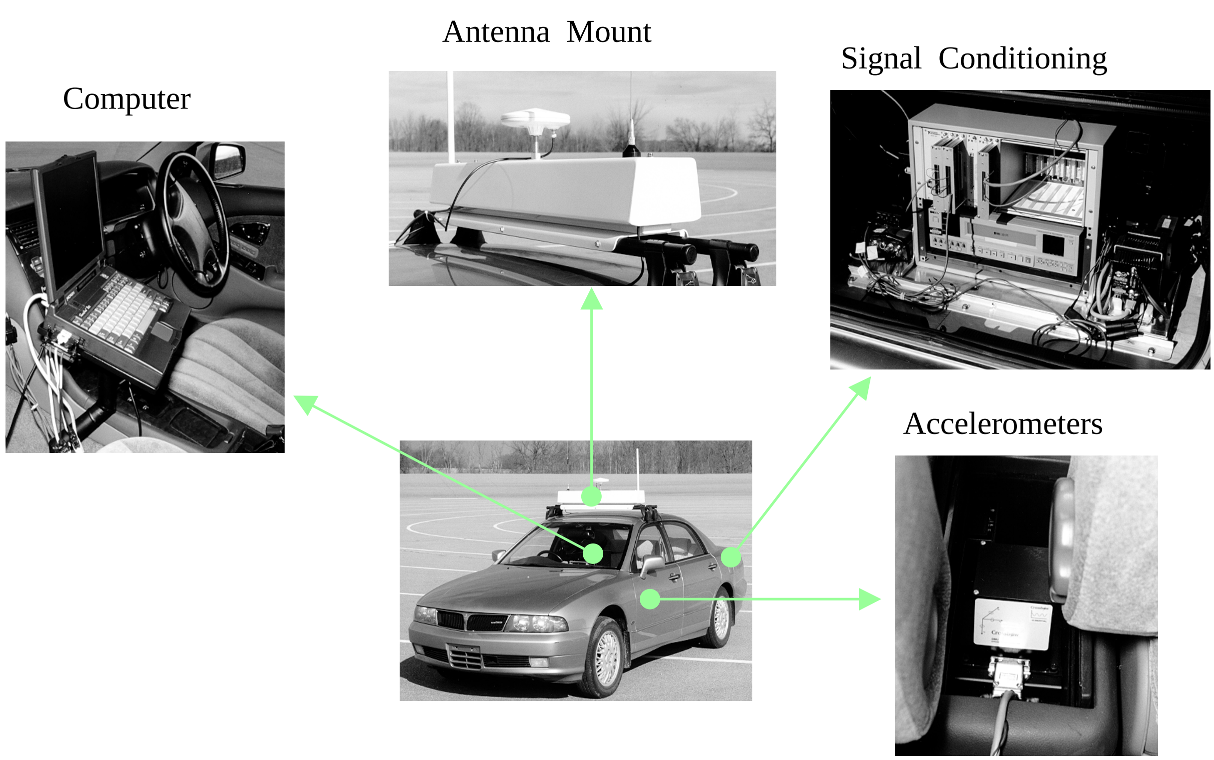


The Mitsubishi Diamante 30RSE is equipped with a Laser Radar FCW System. The FCW system was acquired from Mitsubishi Electronics of America, and was a specially enhanced version of the system sold on the vehicle in Japan in the 1996 model year. The display was an integrated part of the instrument panel next to the clock. The Laser Radar was mounted on top of the instrument panel on the passenger's side of the vehicle.



7.3.2 Equipment Location in the Vehicles

Shown in this group of photographs is the typical equipment installation in a car. The data

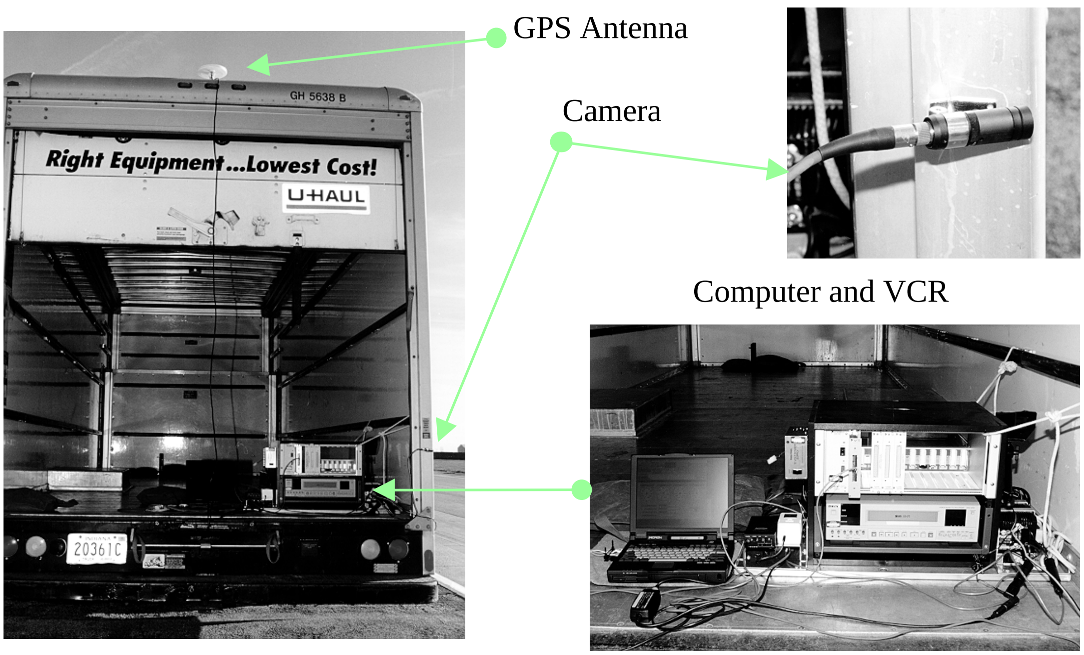


acquisition computer is placed on a pedestal on the passenger side of the car, and is positioned so the driver can operate the program. The antennas were mounted over the center of the car so the GPS antenna was directly over the accelerometer. The accelerometer was mounted in the center of the car between the driver and passenger seats. The rest of the equipment was mounted to a rack and placed in the trunk of the car.

7.3.2.1 Truck One Installation

These photographs show how the equipment was installed in the trucks for executing Test C-13, for which the POV is a motorcycle travelling between two trucks.

The Truck in the Left Lane



It was important to place the GPS antenna at the back of the truck and have the camera looking in the direction of the motorcycle. This provided relative information for the location of the motorcycle during the test.

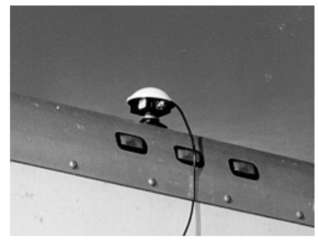
7.3.2.2 Truck Two Installation

Only GPS information was necessary for the second truck. The GPS antenna was mounted over the cab. The drivers of the trucks were instruction to maintain a relative position with each other by being able to observe the other driver during the test.

Truck in the Right Lane

Computer and GPS Receiver

GPS Antenna



7.4 Evaluating the Test Methodology

This section describes the approach that was used to evaluate the FCW system test procedures and data analysis methods developed by CAMP. There are several areas that were evaluated. The primary focus of the evaluation is whether the tests provide a reasonable certainty that a FCW system satisfies the minimum functional requirements. Additional concerns are that the tests be repeatable and practical to execute. Execution of the plan described provides an initial assessment of how well the test procedures and data analysis procedures satisfy these concerns. Chapter 5 covered the Test Methodology and Chapter 6 covered the Vehicle Countermeasure Data Analysis. The test procedures are to evaluate whether a FCW system complies with the minimum functional and performance requirements developed in Chapter 4. For completeness, the test procedures were evaluated to determine whether there is at least one test for each of the requirements included in Chapter 4.

The philosophy set forth when the test procedures for FCW systems were developed was that the tests should be executable by a variety of organizations and at a variety of existing track facilities. This required test specifications that would be interpreted the same way by different test engineers and that would accommodate the differences in the tracks and standard practices at different testing facilities. In addition, the tests were designed to be independent of the sensing technology used by the FCW system. In particular they need to be applicable to systems based upon millimeter wave radar, laser radar or video sensors. The tests are for use by FCW system suppliers during the development of products, by vehicle manufacturers to qualify systems, and by independent organizations to evaluate FCW systems.. A major consideration was to devise tests that would produce consistent results when executed at different locations. Three sites were selected as representative of those accessible by the organizations that would execute the tests. These were the G.M. Milford Proving Ground near Milford, MI, the Ford Motor Company's Michigan Proving Ground near Romeo, MI, and the Transportation Research Center near East Liberty, Ohio.

Evaluations were performed in five areas:

Completeness of the tests (coverage of all requirements)

Correlation to performance during typical driving

Test procedure understandability

Test procedure executability, including driving maneuvers, cost, and time required

Test procedure sensitivity, including sensitivity to site and props, test team, path tolerances, FCW system settings and pass/fail criteria.

Some aspects of the Testing Methodology were evaluated by executing tests while others were done by expert review and analysis. The evaluation issues that did not require actually executing tests included the following:

Determining conflict between the test procedures and established practices at each of the proving grounds

Verification that sites exist for all tests at all three test facilities

Analysis of cost

Analysis of sensitivity of final pass/fail to selected test weights

Public road testing to verify that the tests reflect real-world countermeasure performance

In addition, this section covers the results of the evaluation and suggested improvements to the functional requirements and test procedures based upon the experience of actually running some of the tests on two different FCW systems.

It is noted that the performance of the countermeasures used during testing is not discussed. The performance of specific systems is not a primary interest in this project, except for the insight or understanding that unexpected behaviors provide. Furthermore, agreements with the countermeasure suppliers prevent any performance data from being released.

7.4.1 Test Procedure Execution

This section describes the details of the evaluations that were conducted by executing tests on a test track. To select the tests that were executed, candidate tests were rated as to how likely it was that their execution would expose issues that would suggest improvements to the test methodology. This rating was done by the staff at CAMP after consultation with the staffs at the GM and Ford proving grounds. The issues that were considered included (1) safety, (2) driving maneuver tolerances, (3) set-up and execution time, and (4) sensitivity to site, props, testing team, path or FCW system settings. This ranking identified five tests that were highly likely to expose issues that would suggest improvements to the test methodology. The highlighted tests in Table 7-2 and Table 7-3 are those that were selected and executed.

Test	Test name	Use to Address	Priority
C-1	100 kph to POV stopped in travel lane	Sens. to props	low
C-2	80 kph to POV at 16 kph		
C-3	100 kph to POV braking moderately from 100 kph	Safety	HIGH
C-4	100 kph to POV parked under overhead sign		
C-5	100 kph to slowed or stopped motorcycle		
C-6	SV to POV stopped in transition to curve (wet)	(a) Safety (b) Sens. to teams	(a) HIGH (b) medium
C-7	SVto POV parked on a curve		
C-8	SV to slower POV, in tight curve	(a) Sens. to site (b) Sens. to teams	(a) medium (b) low
C-9	POV at 67 kph cuts in front of 100 kph SV	(a) Safety (b) Sens. to path (c) Executability	(a) HIGH (b) HIGH (c) HIGH
C-10	SV at 72 kph changes lanes and encounters parked POV		
C-11	100 kph to stopped POV, with poor visibility.		
C-12	POV brakes lightly while SV tailgates at 100 kph.		
C-13	Greater size and equal distance (2 trucks, 1 m'cycle)	Safety	HIGH
C-14	Greater size and greater distance (1 truck, 1 m'cycle)		
C-15	100 kph to 32 kph Truck		
C-16	C-6, but with dry pavement and poor markings		
C-17	24 kph to stopped vehicle	Sens. to FCW setting	medium

Table 7-2 High-Priority Crash Tests Selected for Evaluating the Test Methodology

Test	Test name	Use to address	Priority
N-1	Overhead sign at crest of hill	Sens. to site	medium
N-2	Road surface objects on flat roads	Sens. to props	very low
N-3	Grating at bottom of hill		
N-4	Guardrails and concrete barriers	(a) Sens. to path (b) Sens. to FCW setting	low low
N-5	Roadside objects along straight and curved roads (wet)	(a) Sens. to prop design (b) Sens. to site	(a) medium (b) low
N-6	U-turn with sign		
N-7	Slow cars in adjacent lane, in curve	(a) Sens. to site, (a) Sens. to team	(a) HIGH (b) HIGH
N-8	Trucks in both adjacent lanes		
N-9	N-5, except with poor lane markings		

Table 7-3 High-Priority Nuisance Alert Test Selected for Evaluating Test Methodology

The five selected tests were executed at the sites indicated in Table 7-4. They were all executed with two different commercial FCW systems, one based upon a microwave radar and the other based upon a laser radar and video camera. A combination of engineers from CAMP and test drivers from the proving ground was used to execute the tests.

The following sections describe the execution of the five tests. Findings that affected the final set of proposed test procedures are reported.

Test	Site(s)	Tests Executed?	
		Radar	IR
(C-3) 100kph to POV braking moderately hard from 100kph	GM	Yes	Yes
(C-6) SV to POV stopped in transition to curve (wet)	TRC GM	Yes	Yes
(C-9) POV at 67kph cuts in front of 90kph SV	GM	Yes	Yes
(C-13) Greater size, equal distance (2 trucks & motorcycle)	TRC	Yes	Yes
(N-7) Slow cars in Adjacent Lanes	TRC	Yes	Yes

Table 7-4 Sites and Countermeasures Used to Execute High-Priority Tests

7.4.1.1 Test C-3: 100 kph to POV Braking Moderately Hard from 100 kph

Validation Issues and Findings

In Test C-3, the SV follows at a fixed headway behind a POV at 100 kph (see Chapter 5 for detailed test procedures). The POV begins to brake moderately hard and the SV continues at constant speed until either the crash alert is triggered or the range drops to less than the “too late” onset cutoff of Chapter 4. This test explores the ability of the countermeasure to function as required with a decelerating lead vehicle. The test is also used to collect data for use in estimating expected exposure to in-path nuisance alerts for the countermeasure.

This test was selected for inclusion in the validation work to determine whether such a maneuver was safe for execution by professional drivers. In this test, the POV initiates the conflict, so careful coordination is required. The result of the test track validation experiments was an understanding that the maneuver is safe, with care and planning.

Test Execution and Discussion of Data

Test C-3 has been revised since it was performed for validation purposes; the maneuvers are now milder than those that were executed and reported in this section. The test was executed with a lead vehicle deceleration of –0.4g; the revised procedures use –0.32g. (The revision was to accommodate the alert onset timing requirements based on the human factors experiments of Chapter 3.)Thus the finding that the test is executable at the higher deceleration level ensures that the test is executable at the lower deceleration level.

The test involves the SV and POV traveling on a straight, level, dry road with clear lane markings at approximately 100 kph with the SV lagging behind the POV by 2 to 2.5 seconds. The POV suddenly begins to brake at approximately 0.4 g while the SV continues at a constant speed. The test ends when the most imminent crash alert occurs or the SV comes within 90% of the minimum acceptable most imminent crash alert distance, whichever comes first. If the test conditions are nominal then the minimum acceptable most imminent crash alert distance would occur when the vehicles are about 40 meters apart, using the requirements at the time. They reach a condition of 90% of the minimum distance (as the POV continues to decelerate) when they are 34 meters apart. The test procedure includes tolerance for the speeds, range at braking onset, lateral offset, lateral position in the lane, and heading angle. There are also tolerances on the flatness and straightness of the roadway. (With revision of the test, the target range is 54 m, compared to the 34 m assumed in this section.)

The test trials were conducted on the 1.6 km (1 mile) long Military Straightaway at GM's Milford Proving Ground. Both the TRC and Ford's Romeo Proving Ground have straight tracks of similar length. Each trial began at one end of the track with the SV and POV stationary and about 65 meters apart. The data recording equipment was started and then the drivers would accelerate to 100 kph. The driver of the POV would then engage the cruise control, drive to the other end of the track and then brake at 0.4 g. While the POV was at a constant speed, the driver of the SV would adjust the cruise speed or use the accelerator until the SV was between 60 and 65 meters behind and traveling the same speed as the POV. When the POV began to brake, the driver of the SV would continue driving at the POV at a constant speed until the minimum alert distance was achieved.

To achieve the desired headway, the driver of the SV would engage the cruise control at slightly under 100 kph. The range between the SV and POV was continuously displayed to the driver of the SV. This range reading was used to guide the driver who would adjust the cruise control speed or use the accelerator to achieve the target distance. Typically, this synchronization could be achieved by the time the vehicles had traveled 1 km from the start.

To guide the drivers in the braking maneuver, markers (construction cones) were placed by the side of the road as shown in Figure 7-6. On the right side of the road was a marker (A) at which the driver of the POV was to start braking. The digital display from an accelerometer was placed on the dashboard of the POV so the driver could have real-time feedback for controlling the deceleration. Further down the road was a marker (B) at a distance corresponding to the travel if the POV braked for four seconds at 0.4 g. When the POV came abreast of this marker the driver would take his foot off the brake and swerve ½ lane to the right. The four second delay between the first marker and the second marker on each side were calculated to bring the relative speeds and distances between the POV and SV to a condition such that the range at that time was less than 90% of the minimum acceptable most imminent crash alert distance. On the left side was a marker (A) 62.5 meters before the first marker on the right. The driver of the SV would check that the SV was even with this marker at the time the POV began braking. Further down the road was a second marker (B) on the left side of the road. This marker was at a distance corresponding to the travel of the SV at 100 kph for four seconds. When the SV came abreast of this marker the driver would swerve ½ lane to the left and then begin braking.

For practice runs, the position of the second marker was placed closer to the first. Practice began with a delay of 1 second from the onset of braking until the evasive maneuver. The second cone on each side was moved down the track between trials until the delay from onset of braking to the evasive maneuver was four seconds.

It was found that the digital display of the lead vehicle deceleration was updated too slow to provide good real-time adjustment of the braking level. Instead, the driver of the POV would read the braking level during a trial and use that to adjust the pressure he placed on the brake during the next trial. A mechanical acceleration indicator such as those which use a fluid in a U-shaped glass tube has been found to provide better real-time feedback to the driver. Another alternative would be to install an automatic braking system in the POV as was done for the human factors studies in this project.

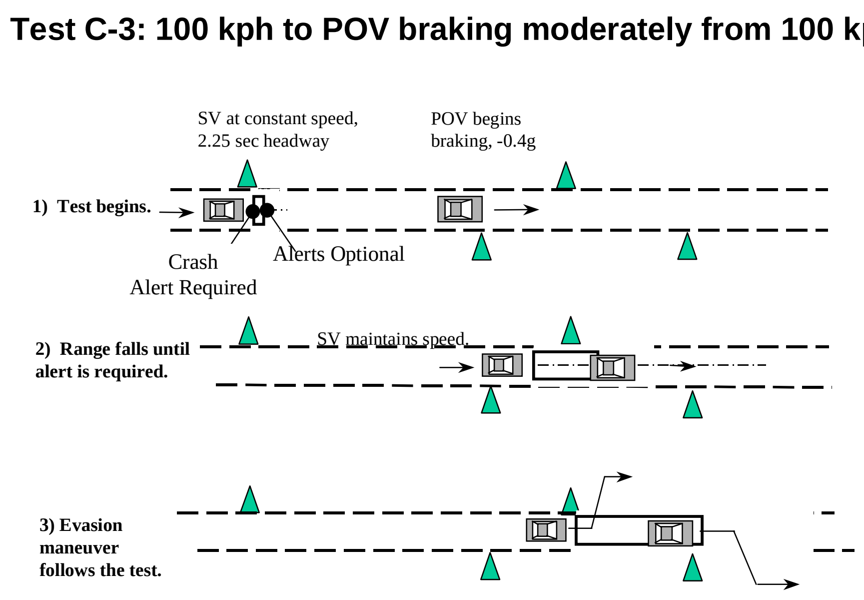


Figure 7-6 Driving Cues for Test C-3

Seventeen trials were performed once the orchestration and practice phases were complete, including 7 trials with the radar-based countermeasure and 10 with the laser radar system. An example of the vehicle motions and alert requirements during the trials is shown in Figure 7-7. Data showing the longitudinal motions and requirements are shown in the top plot of the figure, and lateral components are shown in the bottom half. In this example, the SV and POV speeds are initially near 100kph and the range between the vehicles is approximately 61 meters, per the specifications in the interim test procedures. The POV begins to brake near the 8 second mark in the plots, as shown by the deceleration levels and the falling POV speed. The range between the vehicles also begins to fall.

The lower plot in Figure 7-7 includes two traces representing the lateral positions of the center of the vehicles, measured relative to the road. In this example the SV runs slightly to the right of the POV as they approach the point of braking, but within the test specifications of 0.5 meter.

In both plots, notice the vertical line at about 11.5 seconds. This indicates the moment that the most imminent alert becomes allowed by the requirements in Chapter 4. This change is due to the decrease in the range that is caused by the slowing lead vehicle. A bar running along the abscissas changes from light shading (most imminent alert prohibited) to a hatched pattern to indicate that the most imminent alert is now permissible. About one second later, a second vertical line indicates that the most imminent alert is now required. The bar changes from hatched to solid black. The alert requirement changes in this test due to the decreasing range.

Consider the kinematic conditions at the moment that the most imminent alert becomes required: the SV is closing on the POV at 50kph (13.9 m/s) and the range for the various trials falls between

35 and 38 meters. Thus the time to collision is less than three seconds. As the POV continues to brake, the range and the time to collision drop quickly; the drivers of these 17 trials felt safe with this test, but there is a need for careful orchestration and execution.

Returning to Figure 7-7, as the goal of reaching the crash alert minimum required range is achieved, the POV steers to its right and the SV to its left in the planned evasive maneuver.

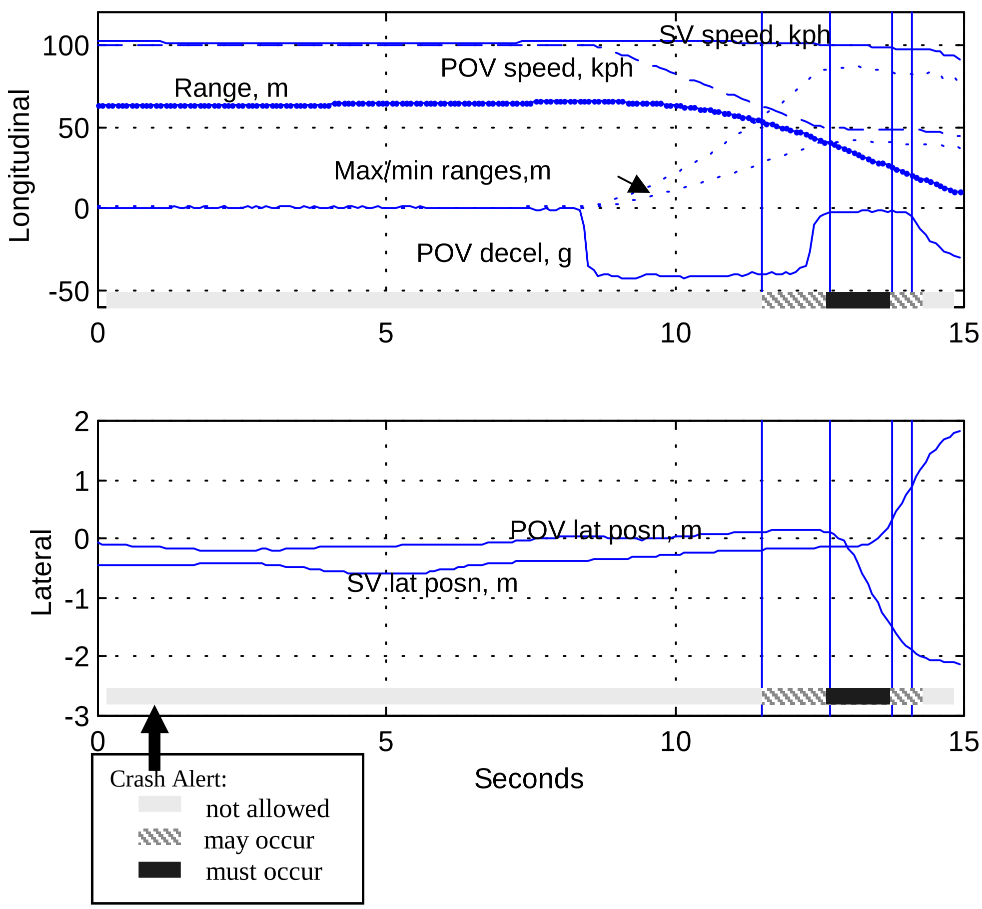


Figure 7-7 Vehicle Motions and Alert Requirements During a Test Trial: Test C-3 100 kph to POV Braking Moderately From 100 kph

The POV has released its brakes slightly before this goal. In the 17 trials, several trials showed one or both vehicles beginning there evasive maneuver slightly early (80 to 250 msec early). This can be avoided by placing the evasion cue cones slightly further down the road – the difference between an ideal step input braking maneuver and the actual first-order type response left the POV traveling slightly faster than predicted by the simple cone-placement analysis.

To evaluate the definition of the Test C-3 test maneuver that was given in the Chapter 5, the trial data was examined closely. Specified values and tolerances had been proposed for ten variables, including SV and POV speeds, headway, POV deceleration profile, SV heading angle, SV and POV lateral positions, SV brake switch, and the required range to achieve before beginning the evasive maneuver. The data shows that three requirements were sometimes not satisfied during execution. None of these, however, suggest substantive changes to the test. Two requirements sometimes violated are the average speeds of the vehicles before braking begins. This was caused by the POV speedometer being in error by a few kph at the test speeds, and so both vehicles typically traveled 102 kph with deviations of less than 0.5 kph. A speedometer calibration or more accurate in-vehicle speed indicator would correct this. The third requirement sometimes violated was the requirement that the range should drop to 90% of the minimum required range before any evasive maneuver occurs. The cause and solution for this issue were described earlier.

7.4.1.2 Test C-6: SV to POV Parked in Transition to Curve (wet)

Validation Issues and Findings

In Test C-6, the SV, initially in a straightaway, approaches a curve. The POV is a stopped car approximately 60 to 90 m into the curve. This test studies the countermeasure's ability to track targets through changes in curvature. A wet road is used to ensure that the FCW system is able to sense the curvature change with wet roads, a common condition that may challenge some sensing modalities.

This test was selected for execution during the validation phase in order to investigate two key issues: executability and sensitivity to the test site (curve radius). The primary concerns regarding executability were (1) the safety of running a test involving an evasive lateral maneuver in a curve on wet pavement, and (2) the ability to hold a prescribed lateral position in a transition to a curve. The primary concern involving test site curvature was to minimize the possibility that a test executed on different curves would give different pass/fail results. Executing this test would require addressing the availability of curves at the different sites. allowed the opportunity to to determine how to promote repeatability of the test across different test sites (proving grounds). The test procedures proposed in the interim report required that this test be run at a fixed speed (72 kph) on a track with a radius of curvature that falls within a prescribed bound. The data from executing this test was expected to provide feedback regarding this approach.

Data is presented and discussed in detail below, but the key findings are now stated. The executability issues did not lead to any revisions of the test procedures. It was found that the evasive maneuver (steering around the POV) involves no discomfort for the driver and presents no significant safety concerns beyond common testing work. It is argued that drivers can meet the required lateral position tolerance (0.5 m) with the help of driver aids, even though a tendency to "cut the curve" appears at the transition to the curve.

Significant revisions were motivated by the investigation of curvature issues, however. These revisions are incorporated in the test procedures of Chapter 5, and follow from two findings. First, the available curves at the test track sites considered are rather limited and are not representative of public roads either in the radius of curvature values or the superelevations. This is especially true when looking for transitions into or out of curves. The available curves are typically tighter than required in the first proposed test procedures, with larger superelevations than assumed in the original instructions (which used AASHTO guidelines for speed/curve/superelevation relationships). The second finding was that the radius of curvatures available at the different facilities are quite different in some cases, and without care the procedures will not provide a FCW system the same "look" at different sites. For example, at the moment of required alert, the POV may appear 8 deg to the left of the SV's heading at one test site and 4 deg at another. This is considered an important element of tests involving curves, and the variation was considered unacceptable.

The speed and radius of curvature requirements were revised (e.g., Test C-6) to resolve these concerns. See the test description of Test C-6 in Chapter 5 for the approach taken. With the new approach, the azimuth angle to the POV at critical moments in the test is approximately the same across a wide range of allowed curvatures. SV heading angle tolerances were tightened to improve the repeatability of these tests between trials at the same site. Together, the revisions based on these findings provide requirements that allow testing on a wider set of curves, provide the FCW similar "looks" at different curves, and still involve curvature/speed settings that are realistic public road scenarios.

A secondary observation involved lane markings at the testing sites. It was found that the pavement geometry at both locations satisfied the test requirements but the lane markings at those locations did not meet the requirements. At the GM Proving Ground there was a distance of about 100 m between the end of the lane markers on the straight section and the beginning of the curve. Furthermore, the SV had to cross over markings for the curve that lead into the black lake area. At the TRC there was a jog of about 1.5 m in the lanes at the transition and there was a spiral section between the straight and circular sections of the path. These conditions are not consistent with normal public road marking conventions and were, therefore, not within the test requirements. These deficiencies could be remedied by changing the lane markers (either permanently or with temporary striping techniques) at each location to meet the test requirements.

Test Execution Description and Data Discussion

The test is conducted on a track with a straight section that leads into a curved section. The POV is parked in a traffic lane on the curve near the end of the straight section (see Figure 7-8). The straight and curved track leading up to and around the POV are wet. A trial begins with the SV traveling down the straight track - the validation trials were executed at 72 kph, as required by the original test procedures. (Changes to the speed and curvature requirements of the test, based on the validation work, are discussed below.) A trial ends when either the crash alert occurs or the SV has come within 90% of the minimum allowed distance for crash alert onset. Once the trial has ended the SV driver steers to avoid the POV.

Test C-6: 72 kph to POV stopped in transition to curve (wet)

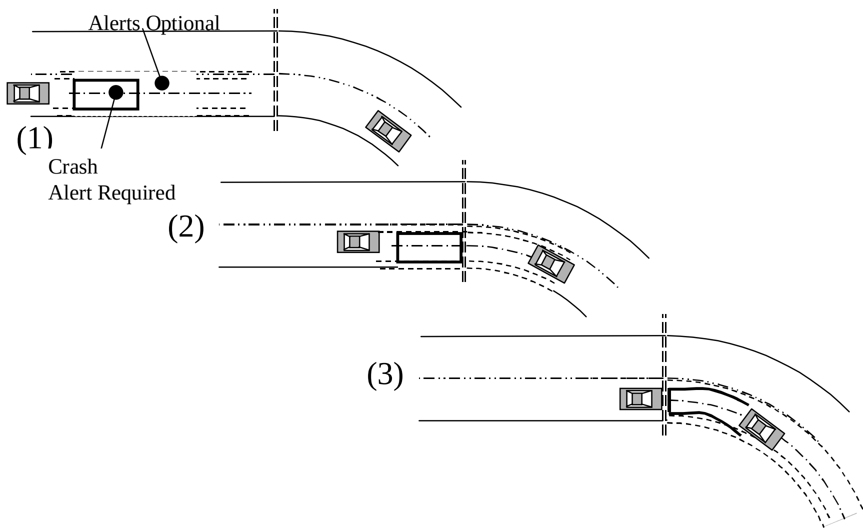


Figure 7-8 Required Test Maneuver for Test C-6

The tests were conducted at two site: the Vehicle Dynamics Test Area (VDTA) at GM's Milford Proving Ground, and the Vehicle Dynamics Area (VDA) at the TRC. Both locations include a large paved “black lake” area with loops at opposite sides of the rectangle (see Figure 7-9 and Figure 7-10). At both locations there is a marked two-lane straight section on the black-lake area of the track. This straight section leads into the 2-lane curved section of road. A similar track exists at Ford's Michigan Proving Ground.

The POV was placed 100 m from the beginning of the curve. A traffic cone was placed where the SV could begin its avoidance maneuver (90% of the minimum allowed crash alert onset distance). Since the trials were run assuming the original timing requirements, this was 64.2 m from the POV, as shown in Figure 7-8. For each trial, the SV accelerated to speed. The driver engaged the cruise control and the SV approached and entered the curve while staying near the center of the lane. When the marker was along side the SV, the driver would turn to avoid the POV. It was raining when the test was run at the GM Proving Ground. At the TRC, a water truck was used to keep the track wet.

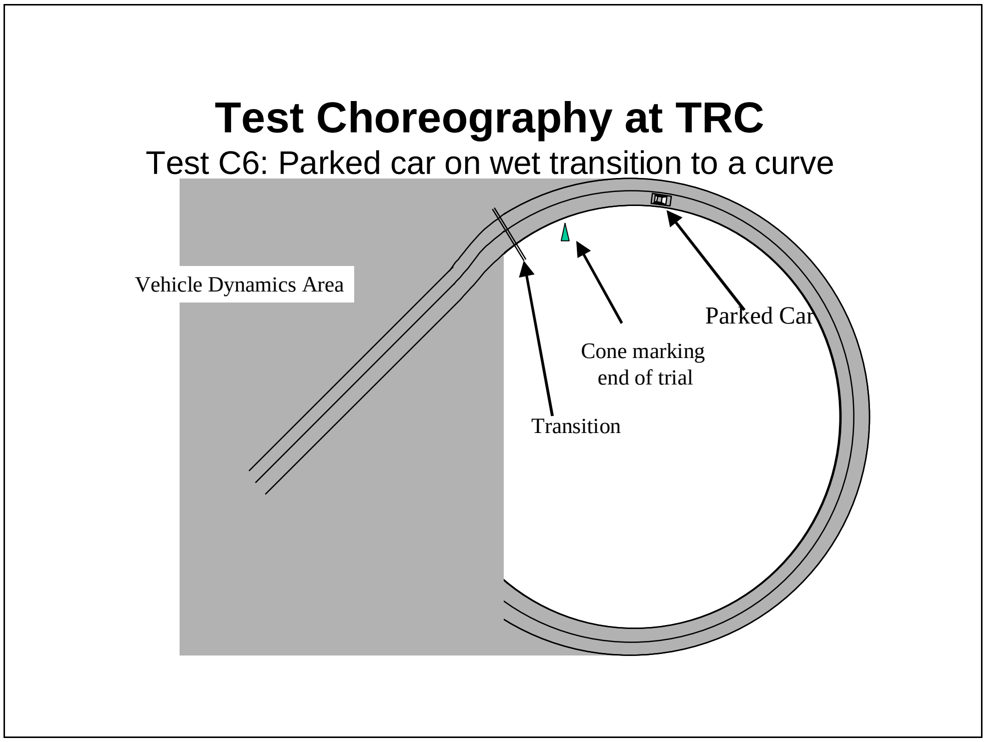


Figure 7-9 Test Site at Transportation Research Center for Test C-6

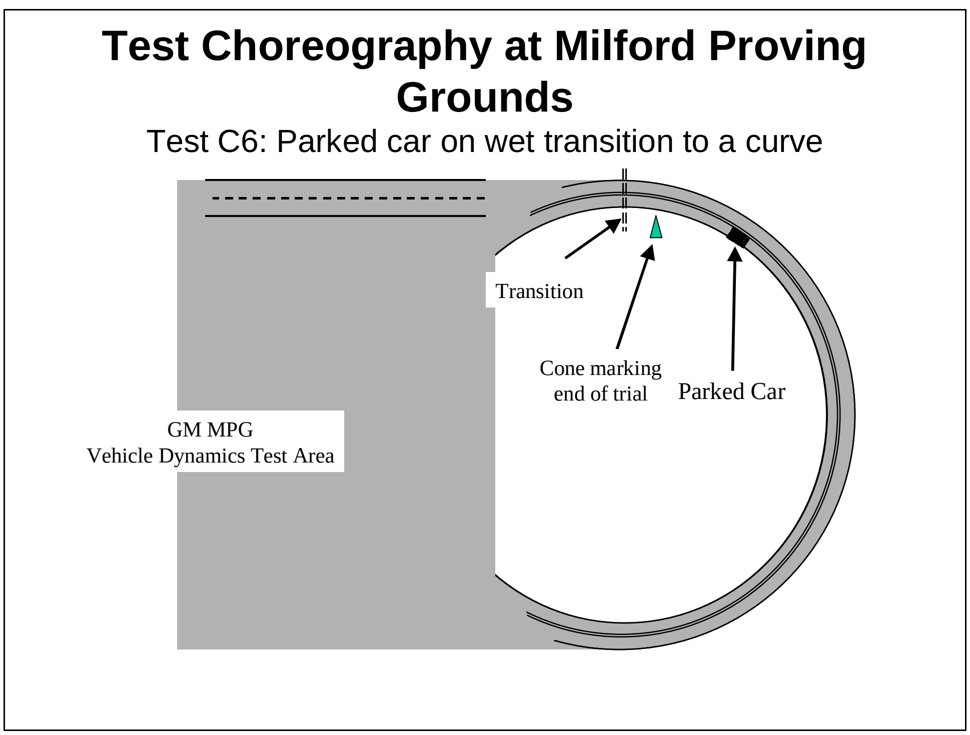


Figure 7-10 Test Site at GM Milford Proving Ground for Test C-6

Sixteen trials were executed at the original SV speed of 72 kph at the TRC. This included eight each for the laser radar and the microwave radar FCW systems. Another 8 trials total were run at 88 kph (55 mph) and six trials total for 56 kph (35 mph), again split evenly between the two FCW systems. Figure 7-11 shows results from eight of the 72 kph trials, split evenly between the FCW systems..

The top plot in Figure 7-11 shows the lateral position of the SV, relative to the road, plotted against the distance the SV has traveled along the road from an arbitrary reference point ("down-road distance"). Both values are computed from onboard DGPS measurements and a survey of the test site. The path of the SV for a particular trial is represented by a trace that begins at the left of the figure and moves to the right as the SV travels toward the POV. The trace moves downward when the SV drifted right in the lane, and moves upward when the SV drifted left. The leftmost vertical line on the plot indicates the down-road position at which the SV front bumper crosses the transition from straightaway to curve, which is close to the 760 m point. At that point, it is 100 m from the rear of the POV, which is represented by the rightmost vertical line (at 860 m). As the trials begin (left region), the range from the SV to the POV is great enough that crash alert onset is not allowed, using the requirements of Chapter 4. It is not until the SV crosses the transition to the curve and travels another 10 m that a crash alert onset is allowed, and yet another 15 m before the crash alert onset is required. The middle two vertical lines indicate these points, which are approximately 90 and 75 m from the POV. Note that 72 kph is 20 m/sec, so that the crash alert onset must begin within a 0.75 sec window.

Two results are clear from the top plot in Figure 7-11. First, driving the SV to within the required distance (63m here) involves no discomfort for the drivers, who usually went within 50 m before beginning the maneuver. Second, the requirement on SV lateral position (within 0.5m of the lane center) is not met. The variation in the lateral position among the eight trials shown, at any given down-road position, does remain within 0.5m of a downroad position-dependent offset, but this offset varies. Two factors contribute to this. First, "cutting the curve" is seen in the data here and in other tests. Without aids for lane-keeping, drivers tend to cut the curves by a fraction of a meter. Second, the survey of the road geometry was hindered by the non-standard lane markings described above. The surveying involved dead reckoning of lane position near the transition. Both of these are considered by-products of the pilot nature of this testing, and did not lead to revisions of test procedures.

The bottom figure plots an "azimuth" angle against the down-road distance. The azimuth angle is defined here as the angle, at the SV, between the SV heading direction and the line of sight between the SV and the POV. (The heading direction is computed using DGPS position estimates of the CG.) Azimuth angle is important because FCW sensing modalities currently have limited field of views that may be challenged by this test. As the POV approaches the transition to the curve, the azimuth builds to a maximum value of about 6 degrees (positive indicates the POV appears "to the right" from the SV perspective). The azimuth then drops as the SV begins to turn toward the POV. The avoidance maneuver is clearly seen in this trace at about 800 to 820 m, as the SV turns toward its left.

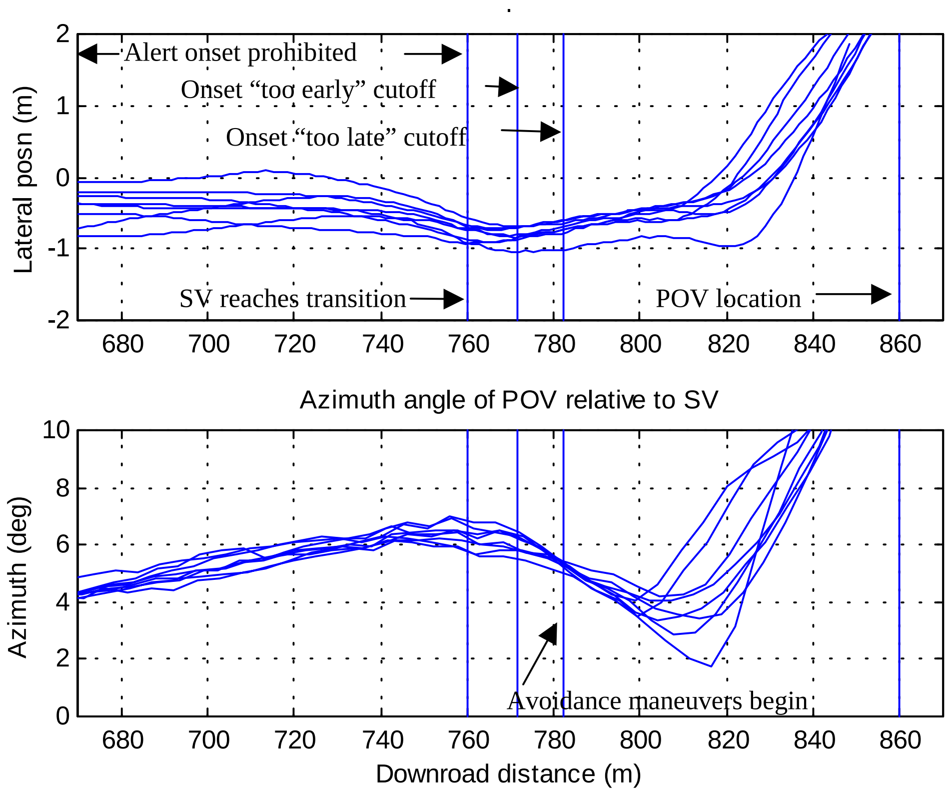


Figure 7-11 SV Lateral Position and the Azimuth Angle To The POV: Test C-6 Parked Car in Transition to a Curve

7.4.1.3 Test C-9: 67 kph POV Cuts in Front of 100 kph SV

In this test, the SV is initially traveling at constant speed in a given lane on a straight, flat, dry road. A slower-moving POV, which is initially traveling in an adjacent lane, changes lanes so that it cuts in front of the SV. The POV enters the Alert Zone at a range which is less than the minimum required range for a crash alert, as shown in Figure 7-12 below. The test determines whether the countermeasure crash alerts occur at appropriate times. The appropriate times are a function of both the lateral position of the POV, relative to the SV, and the combination of range, range rate, and perhaps relative longitudinal acceleration between the two vehicles.

The test specification requires that the slow vehicle (the POV) travel at 65 kph while the fast one travels at 100 kph. The test requirements include tolerances on the range and lateral speed of the POV when it crosses the outer and inner boundaries of the Alert Zone. It also includes tolerances on the speeds and the heading angle of the SV.

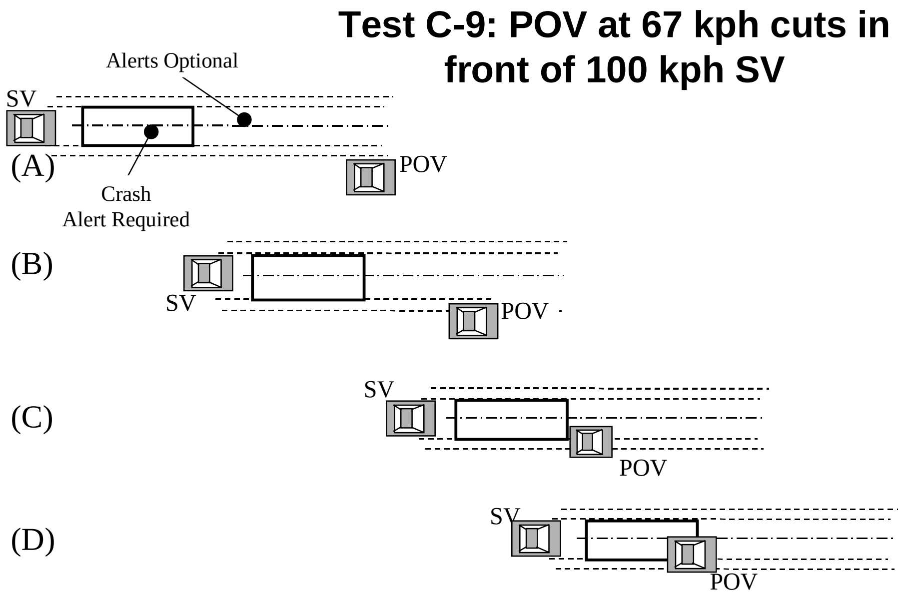


Figure 7-12 Sequence of Required Vehicle Motions for Test C-9 (Cut-In)

The test trials were conducted using the north end of the Vehicle Dynamics Test Area at GM's Milford Proving Ground. This test is more difficult to stage than the two described previously. Vehicles traveling at different speeds must arrive simultaneously at their respective locations for the start of the lateral maneuver. To accomplish this a circular track was set up with markings that helped the drivers get synchronized. There were 8 marks around the circle for the SV and 12 marks around the circle for the POV. The vehicles would be synchronized if they were passing their respective markings simultaneously. Each trial began with the vehicles parked at the location marked start. The data recording equipment was started and then the drivers would accelerate to their respective speeds. The drivers of the vehicles would then engage their cruise control. A radio was used to communicate between the drivers so that one could tell the other each time a mark was passed. The other driver could then adjust the speed slightly to get synchronized. The POV would travel around the circle 1 ¾ times and then head into the straight track section of track. The SV would travel around the circle 2 ¾ times and then head into the straight section of track.

In the straight section of track there were markers indicating where each vehicle should be when the POV began its lateral maneuver (B). There were also markers to indicate the lateral position and location where the POV should reach its maximum incursion into the lane of the SV (C). Finally there were markers that indicated where both vehicles should be when the distance between the POV and SV had reached 90% of the minimum acceptable crash alert distance (D). This last marker was used as the location where the POV would turn to exit the lane of the SV.

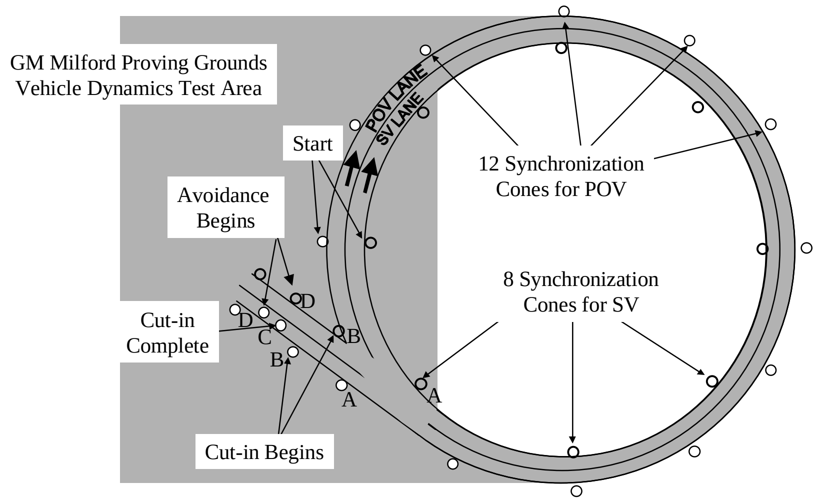


Figure 7-13 Test Choreography for Test C-9 (Cut-In)

The primary concern regarding execution of this test was safety. Therefore, the final test condition was approached in steps. First, the vehicles traveled the course without a cut-in maneuver. This assured that the proper synchronization had been achieved. Once synchronization was accomplished repeatedly the next set of trials included a small lateral maneuver. Immediately after the lateral maneuver was initiated both vehicles would turn away from each other. After several trials the lateral maneuver was increased until the POV was about half way into the lane of the SV. Once there was confidence that this could be done repeatedly then the turn to get out of the lane was delayed in stages. The final choreography had the POV move about half way into the lane of the SV and stay there long enough for the SV to approach within 90% of the minimum acceptable most imminent crash warning. Under the conditions used to execute the test, this distance was 9.94 meters. At that point the POV would move back out of the lane of the SV while the SV continued on a straight path.

Several issues were identified when planning and executing this test. One concern is that the maneuver was performed on a blacktop surface that does not have typical road edges nearby. Furthermore, there were no lane markings to mark the straight section of the course. The lack of lane markings could be corrected with temporary or permanent lane stripes. However, the lack of typical roadside features could not be corrected so easily.

Another concern is that the rules at the GM proving ground limited traveling the circle to 88.5 kph (55 mph). This is less than the 100 kph specified in the test procedure. Furthermore, the SV and POV traveled the circle in different lanes. This caused the speeds to be different than those specified in the test procedure. The nominal speeds used in the validation were 88.5 kph for the

SV and 60 kph for the POV. These limits suggest that the test procedures should be modified to allow a wider range of speeds to be used in the tests.

Several alternatives to the staging of this test are possible. First, the SV and POV could travel the circle in the same lane. This would cause them to be driving the same radius and make the ratio of their speeds independent of the radius of the circle. Another alternative could be to use a long straight track to provide the time to synchronize. The total distance traveled by the SV when driving around the circle to achieve synchronized was 2.4 miles. A 2 mile straight track would likely provide adequate distance for synchronization before the lateral maneuver.

Fourteen trials were performed once the orchestration and practice phases were complete, including 10 trials with the radar-based countermeasure and 4 with the laser radar system. An example of the vehicle motions and alert requirements during the trials is shown in Figure 7-14. The top plot in the figure shows variables describing the longitudinal motions and requirements; lateral components are shown in the bottom plot in the figure. The figure begins with the vehicles emerging from the circular synchronizing loop onto the straightaway. The SV and POV speeds are approximately 90 and 60 kph, respectively, and the range decreases at about 9 m/sec, beginning on the plot at 62 meters at the 0 second mark. The difference between the SV and POV vehicle speeds is fixed during this test. Because the requirements for alert timing used in this validation depend only on closing speed, the maximum and minimum allowable ranges at onset of the most imminent alert remain constant, at about 39 and 20 meters, respectively, as shown in the top plot of Figure 7-14. Because the POV is initially in the left lane and the SV in the right lane, however, the range falls below these requirements-related ranges and still no alert is required.

Near the 4 second mark in Figure 7-14, the POV initiates the cut-in maneuver. Near the 5.2 second mark, the POV has shifted far enough toward the SV that an alert is permissible (indicated by the leftmost vertical line and the changing of the bar from lightly shaded to hatched). The POV continues to move farther into the SV's lane and soon the alert is required. At this point the test is over and the SV begins its evasive maneuver, steering to its right. The POV also steers away so that by the time the range drops to zero the vehicles are once again in different lanes.

As with the previous tests, Chapter 5 specifies several variables to define the vehicles' paths and the test maneuver. The unique requirements for this test include the definition of the POV's lateral motion and requirements for the ranges at which the POV encroaches into the Alert Zone. One minor change is suggested by experience executing the test. The test procedures called for the POV to execute a complete lane change and settle into the center of the SV's lane. This is not required, since the most imminent alert is required before the POV reaches the lane center, and thus the test is effectively over. For this reason, and to increase the safety margin, the POV now aborts the lane change at a time when the test is complete.

Regarding the remainder of the requirements unique to this test, the data shows mixed success in satisfying these. Generally the lateral velocity during the cut-in is acceptable, but often at times the range does not fall within the specified bounds as the POV crosses the two Alert Zone boundaries. Sometimes the range is too large, sometimes too small, sometimes it is acceptable. This does not suggest a flawed test or even a flawed method of orchestrating the scenario. The test can be executed successfully by running two to five trials to get one "acceptable" trial, and/or the drivers' aids can be improved to create a tighter synchronization and a more repeatable vehicle-to-vehicle spacing.

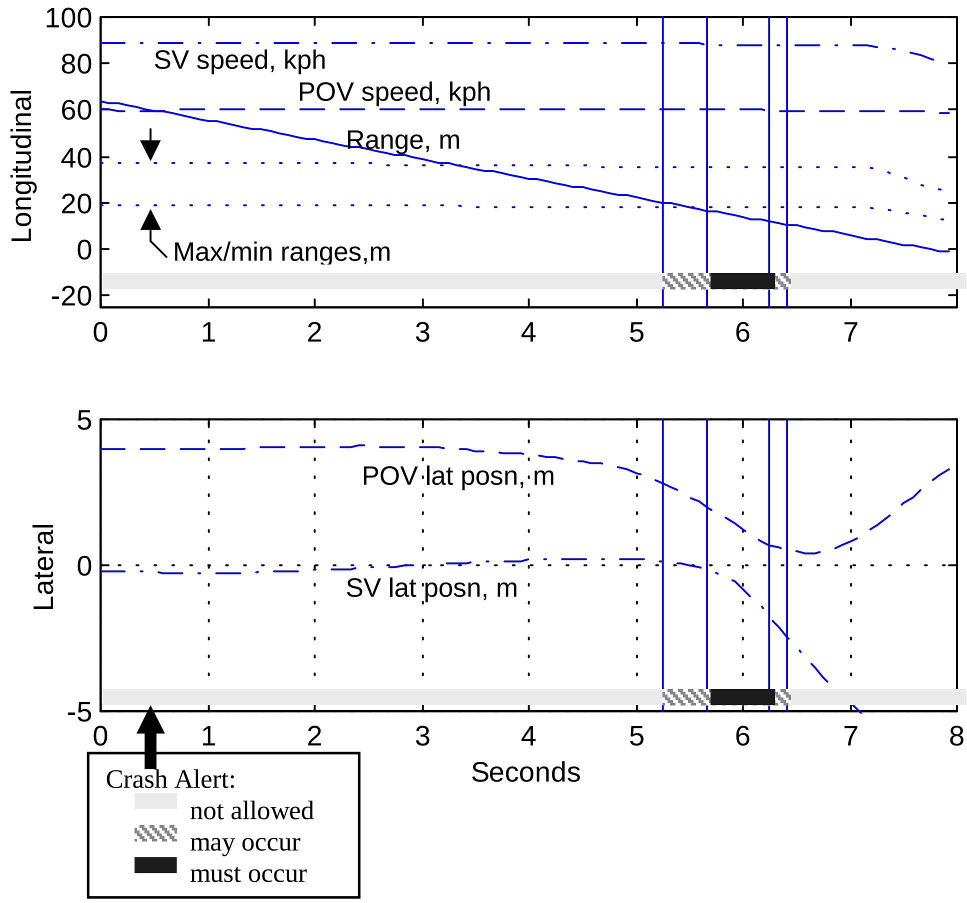


Figure 7-14 Vehicle Motions and Alert Requirements During a Test Trial: Test C-9 60 kph POV Cuts in Front of 90 kph SV

7.4.1.4 Test C-13: Greater Size and Equal Distance

This test requires that the SV travel at 100kph as it approaches a motorcycle between two trucks traveling at 32kph. The test is one of two, which explore the countermeasure's ability to resolve in azimuth a target with a small sensor cross-section, while traveling in traffic. (The other test is a nuisance alert test, without the motorcycle.) All three POVs are traveling at the same speed, and each POV is near the center of its lane. The SV is moving faster, and approaches the three POVs at constant speed while traveling in the same lane as the motorcycle. The test must be conducted on a three lane straight, flat, dry track.

Each trial begins with the SV 200 meters behind the other vehicle. The trial ends when the most imminent crash alert occurs or the SV comes within 90% of the minimum most imminent crash alert distance, whichever comes first.

Test C-13: Greater size and equal distance

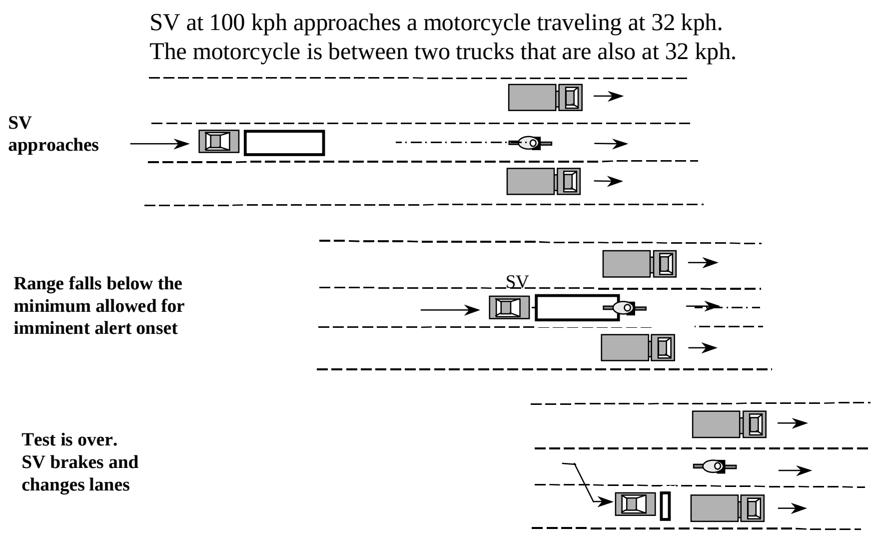


Figure 7-15 Staging Test C-13: Greater Size and Equal Distance

The test trials were conducted at the Skid-Pad area of the TRC. This is a 6 lane straight track approximately 1.5 km long. Two Ford 1995 Model F-700 trucks (24 ft beds, 18,000 lb GVW) were used. The motorcycle was a 1985 Honda Nighthawk, 650 cc motorcycle provided by the TRC. The instrumentation package in the left truck was as previously described for the POV. The video camera was attached to the right rear of the truck so that it could monitor the location of the motorcycle between the trucks. The GPS antenna was placed at the center-rear on top of the truck. A GPS antenna was also placed on the roof of the center-front on top of the right truck with a receiver and computer in the cab to record the GPS data.

Each trial began with the SV parked at one end of the track in the center lane. The other vehicles drove down the track in formation at 32 kph. The trucks stayed in the center of their lanes with their front ends even. The motorcycle would maintain a position in the center of its lane so that its rear end was even with the rear end of the trucks. When the other vehicles were about 500 meters down the track the SV would accelerate to 100 kph and engage the cruise control. A passenger in the SV would monitor a range sensor. As the SV approached the other vehicles the passenger would read the distance between the SV and POVs to the driver. When the distance reached 45 to

50 meters, the driver of the SV would brake hard. This distance was calculated to bring the distances between the POVs and the SV to less than 90% of the minimum acceptable most imminent crash alert distance. As the SV slowed the driver would change lanes to be behind one of the trucks. The lateral maneuver was to make sure the motorcyclist was safe, even if the brakes of the SV failed.

The staging of this test was straight forward. There were two desirable improvements to the instrumentation that were identified. First, the specified speed of the POVs is below the minimum set speed for the vehicles. It would be advisable to provide a cruise control that could be set at the specified speed or to provide a better speed measurement device so that the speed could be controlled more easily. Second, the range measurements used to guide the timing of the braking in the SV were those provided by the countermeasures. It would be advisable to provide an alternative range measurement device, preferably one with a fast update rate (e.g., 10 Hz) and analog gage for the display.

7.4.1.5 Test N-7: Slow Cars in Adjacent Lane at Transition into a Curve

This test is used to determine the sensitivity of a FCW system to slower moving traffic in adjacent lanes. The test requires that a faster moving SV pass two slower vehicles as the SV enters the inner lane of a curve. The test is conducted on a 2-lane track with a straight section that leads into the curved section, as shown in Figure 7-16.

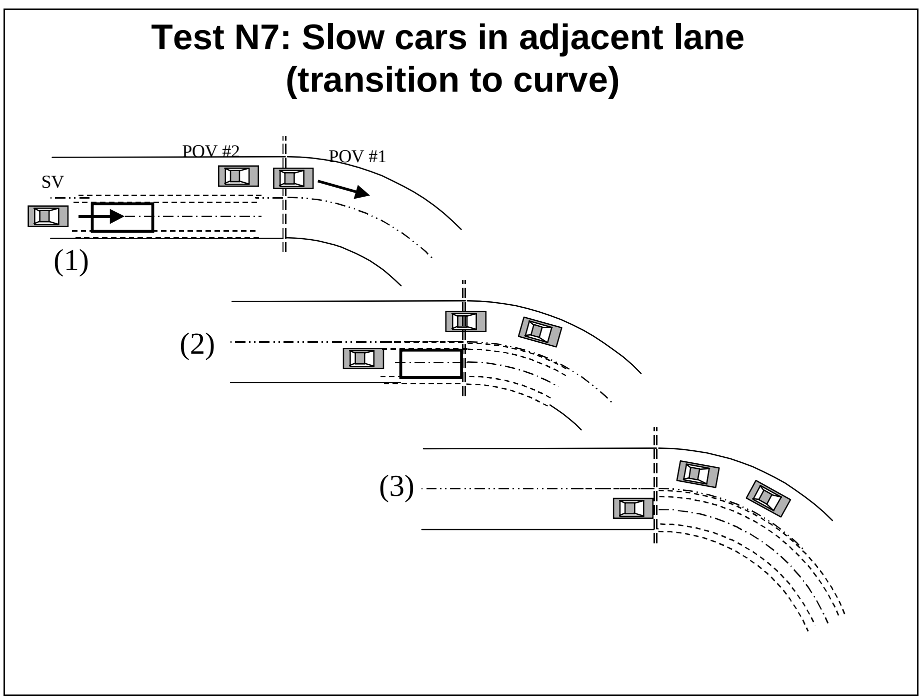


Figure 7-16 Vehicle Maneuver for Test N-7, Slow Cars in Adjacent Lanes

This test was conducted at two locations, GM's Milford Proving Ground and the TRC. At the Milford Proving Ground a track called the Hill Loop was used. This includes a 4.2% down hill grade leading into a curve with approximately a 90 meter radius. The superelevation in the curve was small, similar to that found on public roads.

At TRC a route marked on the VDA was used. It includes two lanes with white solid lines on the outside and a dashed lane marking between the lanes. It includes a straight section that leads into a 110 meter radius curve.

In both locations a set of markers was placed along the track leading to the curve. It was found that at least 45 seconds of travel was necessary to achieve synchronization. One minute would have been better. The markers were placed at intervals beginning at 10 seconds, decreasing to 5 seconds and then to 2 seconds as the vehicles approached and entered the curve.

There were several issues identified while staging this test. The workload on the drivers is high for this test. The drivers of the POVs must maintain their lateral position in the lane as they enter and traverse the curve. At the same time they must maintain a constant speed, a set distance between the first and second POV, and must communicate their position to the driver of the SV so that it can get synchronized. The difficulty is increased because the target speeds for the POVs were below the minimum set point for their cruise control systems. Therefore the driver of the lead POV had to maintain speed and lateral position manually. The workload was decreased somewhat by putting a passenger in the lead POV who would communicate the position to the driver of the SV as the POV passed the markers. The workload could have been reduced further if the POVs were modified so the set speed on their cruise control could be set as low as 15 mph. This combined with an adaptive cruise control on the second POV would have left the drivers only to watch their lateral position in the lane. It would still leave the driver of the SV with a heavy workload; controlling lateral position and adjusting the speed so the SV passes the marks synchronized with the times the POV passes its marks. A longer approach, perhaps a minute or two, would make this more practical.

Finally, this test is a nuisance alert test. As such it needs to be repeated hundreds of times to demonstrate that the frequency of nuisance alerts will be less than the maximum. The current test specification indicates that there should be 567 exposures representing 3 weeks of typical driving. Since several POVs can be used the number of pass can be reduced accordingly. If two POVs are used, as was done in these experiments, and if it takes approximately 2 to 3 minutes per pass, then it would take approximately 9.5 to 14.2 hours to perform this test.

Over 20 trials were performed once the orchestration and practice phases were complete; these trials were split evenly between the radar-based countermeasure and the laser radar system. An example of the vehicle motions and alert requirements during a test trial is shown in Figure 7-18. The top plot in the figure shows variables describing the longitudinal motions and requirements; lateral components are shown in the bottom plot in the figure.

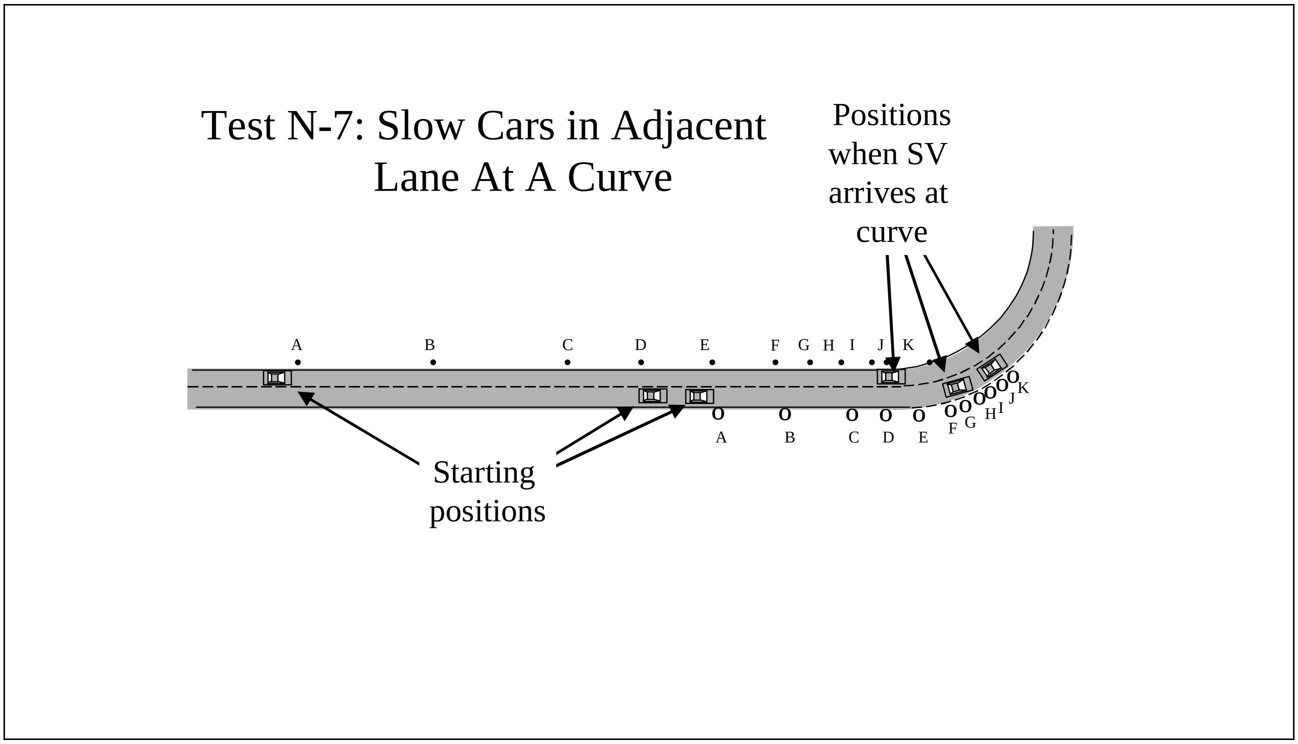


Figure 7-17 Cone Placements Used to Perform Test N-7, Slow Cars in Adjacent Lanes

Figure 7-18 shows data for the SV and both POVs. The top plot shows that the SV and POV speeds are approximately 57 and 28 kph, respectively; the range falls at about 8 m/sec. The top plot shows the range to the rear of both POVs (the difference in the ranges is approximately 15m). Also shown on the plot are ranges associated with the alert timing requirements, as described in earlier sections. The maximum and minimum ranges at alert onset are approximately 18 and 35 meters, respectively. For this test, the single vertical line in the plots indicates the moment when the front of the SV crosses the transition of this track from a straightaway to a constant-curvature curve; this occurs near 5.5 seconds in the figure.

No alert is ever permissible or required in this trial because the POVs keep to the center of the right lane and the SV passes while traveling in the center of the left lane. The second plot in the figure shows the lateral positions of the vehicles, with the SV approximately a lane width (3.6m) to the left of the POVs. Note that all vehicles maintain lateral position rather well, even through the transition.

A major goal of this test is to present a countermeasure with the challenging but common situation in which a vehicle in a different lane briefly appears to be immediately in front of the SV at the same time as the SV is about to encounter a change in road curvature. The example trial was successful in creating this situation with the lead POV. The second set of traces in the bottom plot represent the azimuth angle of the line of sight from the SV to the two POVs during the trial. The angle is measured relative to the SV’s instantaneous heading, and is positive when the POV is to the right. The plot shows that the azimuth angle to the lead vehicle initially undergoes a transition that is due to a bend in the track, and then settles to about 2 degrees between 1 and 4 seconds in the plots. As the POV begins the turn it appears to swing in front of the SV, thus the azimuth drops toward zero between 4 and 5 seconds. When the SV reaches the transition, the lead POV is almost directly in front of it (azimuth near zero), which is the intended situation. After that moment, the SV begins its turn and with the small range, the POV appears to swing rapidly away to the right as the SV begins to pass.

As with the previous tests, Chapter 5 specifies several variables to define the vehicles' paths and the test maneuver. The unique requirements for this test are the need to control speeds and synchronize the SV and POV longitudinal positions at low speeds; and the need for simultaneous manual control of both POV speed and lateral position. Suggestions above addressed these items. The data indicates variability in speeds and lateral positions, as well as variations in the azimuth angles when the SV crossed the transition in curvature. Assuming these drivers' aids issues are addressed, however, test execution data does not appear to require significant changes to the test.

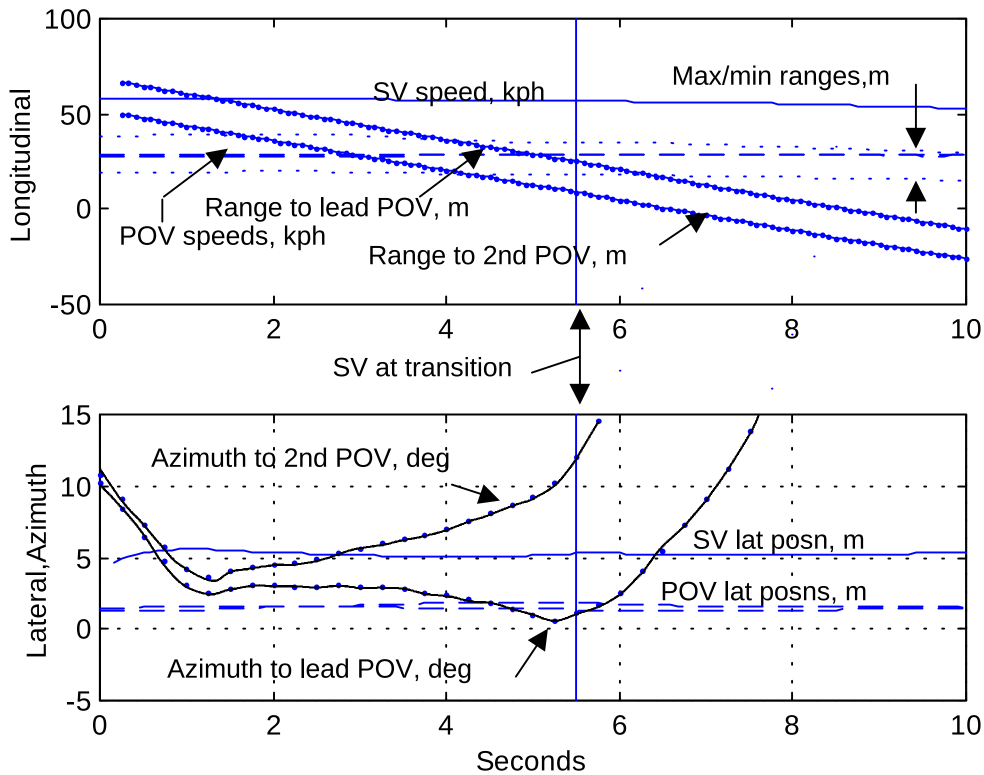


Figure 7-18 Vehicle Motions and Imminent Alert Requirements During a Test Trial Test N-7 Slow Cars in Adjacent Lanes

7.4.2 Validation Results

7.4.2.1 Understandability

The test methodology contained in Chapter 5 is a framework that can be adapted as the functional and performance requirements are refined and as FCW systems improve. It is considered a draft that will be refined and adjusted. Even so, as part of the test procedure evaluation, a review of the procedures was conducted by staffs at the proving ground of each of the partner companies.

Test engineers at Ford and GM were given a copy of the contents of Chapter 5 and a briefing summarizing the contents. They were asked to use the descriptions to determine if there were tracks at their facilities that meet the requirements for the tests. They were also asked to determine if the test procedures could be run within the safety and other work environment standards at their facility.

There was one area identified where the test procedure descriptions should be improved. The first is that the track geometry descriptions for the Nuisance Alert Tests include many references to the AASHTO Guidelines. In particular, there are references to tables in the guidelines that should be used to determine the speed at which tests should be run. The speeds depend upon the radius of curvature and super-elevation of the curves available at the testing facility. The next version of the procedures should summarize the guidelines and provide tables that are more easily interpreted by anyone who want to run the test.

Other observations included that the procedure descriptions need to be clarified and made more consistent. The test engineers thought that most of the procedures could be executed at their facilities. An exception was that the Ford engineers thought their work rules would prohibit placing the guardrails close enough to the track to satisfy the requirements for test N-4.

7.4.2.2 Executability

Five of the tests proposed in Chapter 5 were executed. Some of the tests were selected because they were considered to be potentially challenging tests to perform. The selected tests were demonstrated to be executable, in terms of the critical events of the tests. Regarding the overall paths the vehicles were required to follow, the execution suggests some changes to the test methodology and tolerances. Some changes to the roadway configuration requirements were made to make it possible to use existing tracks. The individual sections 7.4.1.1 through 7.4.1.5 address some possible specific changes; analysis and discussion was used to propagate the changes to all tests.

7.4.2.3 Cost

The total cost to create and integrate the instrumentation packages for the SV and two POVs was approximately $257,000. This included approximately $134,000 for commercially available equipment listed in Appendix E. The remainder of the cost was for custom brackets, assembly, and on-board data acquisition software. Not included is the cost for CAMP software development for post-test data analysis.

Some instrumentation and props that would be necessary for full implementation of the test procedures were not necessary for the tests that were executed for this study. One significant piece of instrumentation would be necessary for test C-11, to measure the visibility. Visibility meters such as those used in meteorology studies, can be acquired for around $10,000. If they did not already exist at the testing facility, full implementation of the test procedures would have to include purchase of additional props, including some portable concrete barriers, metal guardrails and an overhead sign.

7.4.2.4 Time Required

The time required could be divided into planning, setup, execution, and data analysis. The total time to execute and analyze a complete set of tests is estimated to be less than 4 weeks. The initial planning, surveying, and construction of props is not included in the 4 weeks. The table below provides estimates of the time required to execute the selected tests. Estimates include surveying the initial and repeat placement of cones, driving practice time, and test maneuver execution for one trial and for all trials.

Test	**Survey**	**Repeat Setup**	**Practice**	**Execute Once**	**Total Execution**
C-3: Lead vehicle braking	1 hour	15 minutes	½ day	5 minutes	½ day
C-6: Stopped vehicle in transition to wet curve	½ hour	5 minutes	1 hour	5 minutes	2 hours
C-9: Cut in	½ day	1 hour	1 day	15 minutes	½ day
C-13: Greater Size, Equal Distance (2 trucks & M'cycle)	none	none	1 hour	5 minutes	2 hours
N-7: Slow cars in adjacent lane at a curve	2 hours	½ hour	2 hours	3 minutes	15 hours

Table 7-5 Test Procedure Execution Time Estimates

Data analysis time is not included in the table. Data analysis time for these tests will depend on the overall system design for data acquisition, file transfer, and data analysis. If the tests become an accepted means for evaluating countermeasures, it is reasonable to expect that software will be developed to provide a semi-automated means to transform the raw test measurement data into a results sheet documenting test trial validity and countermeasure performance. With this assumption, the data analysis time is expected to fall within the estimated 4-week duration of testing.

The level of data reduction assumed above was not achieved during testing activities -- the data analysis software was developed only to support the validation efforts, and the software needed to be a flexible analysis and learning tool to support study of the procedures themselves.

7.4.3 Sensitivity Analysis

The results of testing an FCW system should not vary, as long as the execution of the tests satisfies the requirements given in the test procedures. To look for undesirable sensitivities of testing results, Chapter 6 suggested that five areas of sensitivity be examined. These areas are discussed below.

7.4.3.1 Site & Props

The sensitivity of the test results to differences in test sites and to variations in the props is studied. Sensitivity to sites relates to three characteristics, (1) differences in surrounding clutter, (2) differences in road geometry, and (3) differences in road markings.

The site chosen for execution of test C-13 demonstrated that surrounding clutter can cause unexpected results. A sprinkler system designed to wet the test track tended to cause one of the countermeasures to generate alerts as it was passed. Once the cause of the alerts was identified, it was simple to run the tests on a different part of the track. There were no other instances where surrounding clutter seemed to affect test results.

The primary concern regarding road geometry is whether differences in horizontal or vertical curvature can impact test results. Two tests (C-6 and N-7) were each run at two locations. In test N-7 (slow cars in adjacent lanes) the vehicle speeds are a function of the radius of curvature of the available track. In test C-9 (parked car on a wet transition to a curve) the speed of the SV is constant while the requirements place bounds on the curve that can be used.

The last concern regarding sites was whether test results would be sensitive to the type or quality of the road markings. In the tests performed, only the Laser Radar system has optical sensors to detect the road markings. There was no observed sensitivity to the differences in the qualities of the lane markings at the test tracks. However, it is recognized that differences in road markings could become more important for future FCW systems.

The only props used during the execution of the tests were the other vehicles. It was observed that there is some sensitivity to the characteristics of the POVs. This led to the conclusion that the test specifications must be more specific regarding the characteristics of the vehicles that are used in the tests.

7.4.3.2 Test Team

The sensitivity of test results to changes in the particular team of engineers and drivers who would execute the tests. This proposal was part of the overall desire to look for possible failures of the test methodology to produce repeatable results. Consider three ways in which the evaluation of a countermeasure's performance in a test may vary among teams of testing staffs:

1. Different interpretations of the testing maneuvers and prop layouts could occur.

2. Different ways of conducting a test could occur if organizations use different assumptions about how tests are conducted.

3. Different vehicle motions could result from individual differences in driving patterns.

These three separate pieces were addressed in different ways. For the first two items, (1) and (2), feedback from proving ground staff at each company was received after they reviewed an interim version of the test procedures document, as described earlier. There were no clear differences in interpretation between the two companies, though it is possible that such differences would become apparent if the groups executed the tests. For item (3), test execution of both Tests C-6 and N-7 was done using different drivers. No significant effect of using different drivers was seen in the countermeasure evaluation results.

7.4.3.3 Path Tolerances

The differences in test results stemming from allowed differences in vehicle path is to be minimized. Consider three elements of the vehicle paths: vehicle speeds, vehicle decelerations, and vehicle lateral positions. Let us consider these elements individually.

First, there is not likely to be sensitivity of test results to allowed variations in vehicle speeds. In practice, vehicle speed variations are quite small due to cruise control systems. Also, for crash-alert timing, performance criteria are given as a function of vehicle speeds, thus compensating for the small differences in speed that are seen. For nuisance alert tests, it is thought to be unlikely that the small changes allowed in vehicle speed (2 kph) will affect the occurrence of nuisance alerts.

Second, the sensitivity of results to vehicle decelerations addresses possible passing or failing of systems during the two tests that include lead vehicle decelerations (Tests C-3 and C-12). Any answers to this are likely to be analytical products because such a sensitivity is likely to be possible only if either the timing requirements or the countermeasure itself include a dependence on vehicle accelerations. Indeed, real sensitivity is likely to result if only one of these (requirements, or countermeasure algorithms) include vehicle deceleration effects. For now, however, the proposed requirements for alert timing depend only on the closing speed and not accelerations. With countermeasures that use only speeds in their timing algorithms, there can be sensitivity to deceleration levels only when the deceleration tolerances allow significant variations in speed profiles, which is not allowed in the procedures. With countermeasures that employ estimates of vehicle accelerations, there may be variations in performance, but the relative significance of the amount is not available from the evaluation work conducted here.

7.4.3.4 System Settings

Some FCWs include driver-adjustable settings to control, for example, the relative timing of alerts. One of the systems used by CAMP includes a rotary dial to adjust alert timing; the other system does not. The Chapter 5 suggested the following approach to testing a system that includes adjustable settings: Testing is conducted with the system set at minimum sensitivity. The reasoning was that crash alerts must occur soon enough, per the minimum requirements, no matter how a driver adjusts the system, and that the driver should be able to maintain that performance while not encountering too many nuisance alerts. Thus there can be no sensitivity of a countermeasure's assessment to any ability to adjust system settings.

Another possible advantage of conducting tests at different settings during the test procedure evaluation phase is to look for unwanted sensitivities within particular tests. Because there was no electronic access to one of the systems alert timing signals, however, such an investigation is not possible.

7.4.3.5 Pass/Fail Criteria

Chapter 6 included an analysis of the impact of small changes in the results from individual tests upon the overall results. A related concern is whether any of the pass/fail criteria have an inordinate impact upon the overall results. There was no indication from the tests that were executed, that small changes in the pass/fail criteria would alter the overall assessment of the unites used in the testing. It was found that, for any particular test, the countermeasures used in this study either passed the tests easily or had far more alerts than would be acceptable. This suggests that small changes in the weights would not change whether a system passes or fails.

7.4.4 Correlation With Performance During Typical Driving

The work described in this section was performed to demonstrate that the test procedures subject FCW systems to a set of scenarios similar to public road situations that may trigger crash alerts. The two FCW systems described in 7.3.1 – a laser radar-based system, and a microwave radar-based system -- were each driven on roads with normal traffic to identify conditions that frequently produce alerts. The vehicles were driven in both urban and rural areas, on residential, feeder, arterial and limited access roads in heavy and light traffic conditions during the day and at night. Data similar to that collected from the SV during track tests was collected during these driving conditions. The videotapes and collected data were analyzed to identify conditions that produce alerts. The test procedures were analyzed to determine if these conditions are represented. Subjective judgments were made regarding whether the results from the track tests are similar to the results from driving on public roads.

A route was selected through southeastern Michigan that is approximately 320 km (200 miles) long. This corresponds to the average distance traveled by a passenger car in one week (Horowitz, 1986). The route characteristics closely approximate the distribution of local, arterial, and highway miles in urban and rural areas during the day and at night, as reported in Stewart and Burgett, 1989. The breakdown of the road types included in the route is shown in Table 7-6. A detailed description of the route is included in the Appendix E, Section E.2.

Road Type	Daytime distance (km)	Nighttime distance (km)	Total (km)
Urban-Local	32.2	7.8	40.0
Urban-Arterial	87.2	17.7	104.9
Urban-Highway	44.4	7.5	51.9
Rural-Local	22.9	6.6	29.5
Rural-Arterial	43.7	11.0	54.7
Rural-Highway	34.4	6.7	41.1
Total for all highways:	264.8	57.3	322.1

Table 7-6 Average Distribution of Driving Conditions

The data collection and analysis were performed by CAMP staff members who have worked on the human factors aspects of the project. The daytime route was driven between 8 a.m. and 4 p.m. on December 14, 1998. The night time route was driven between 7 p.m. and 9 p.m. on December 15, 1998. During the drive one of the researchers drove while the other recorded the time of each alert and the apparent cause.

While driving the selected route the following types of data were collected:

- GPS to provide approximate location
- Vehicle speed
- Video showing movement of vehicles ahead of the SV and roadway clutter in the field of view of the sensor. The video was time stamped to correspond closely with GPS time (within 2 seconds).
- Lateral and longitudinal location of all objects, as observed by the FCW sensor.
- Time and level of each FCW system alert.
- The lateral and longitudinal offset of the primary object when each alert occurs.

Once the data was collected the researchers reviewed the collected data to identify any alerts that occurred for which the cause was not clear. For each of these alerts the ancillary data was reviewed to identify the likely causes. For example, the lateral and longitudinal information about the cause of the alert and the time history of observed objects was used to determine the location and motion of the cause of the alert. Then the video was examined to see what objects had similar motion. This analysis produced a list of conditions that caused alerts. To determine the total exposure to similar conditions the video and other data were again reviewed to determine the total number of times each set of conditions was encountered (including those times when an alert was not generated).

To validate part of the specifications for Test C-9, the cut-in test, the video tape was used to estimate lateral velocities when vehicles changed lanes in front of the SV. While reviewing the video tape, the researchers looked for cut-in instances. They measured how fast the POV made the cut-in by noting how long it took to cross the lane markers in each instance and the approximate width of the vehicle. These provided an estimate of the distribution of lateral velocities when vehicles change lanes in traffic.

The proposed test procedures were reviewed to determine whether they include scenarios similar to those that triggered alerts on the public roads. Two alert-producing conditions were found that were not represented at the time in the test procedures. Modifications to the test procedures were made to include these situations. (Disclosure of the specific conditions is prohibited by agreements with the suppliers of the FCW systems.)

7.5 Summary

This chapter describes activities and testing conducted to validate a test methodology proposed to provide an objective vehicle-level assessment of forward collision warning systems (FCWs). This methodology is described in Chapter 5.

The primary purpose of the validation effort is to assess whether the test procedures are practical to execute and provide a reasonable certainty that a FCW system that passes the tests satisfies the preliminary minimum functional requirements. The proposed methodology is intended to provide repeatable assessments of FCW systems. The tests are designed to be independent of the sensing technology used by the FCW system – in particular, to systems based on millimeter wave radar, laser radar, or computer vision sensors. The tests are for use by FCW system suppliers during the development of products, by vehicle manufacturers to qualify systems, and by independent organizations to evaluate FCW systems. A major consideration was to devise tests that would produce consistent results when executed at different locations. Three sites were selected as representative of those accessible by the organizations that would execute the tests. These were the General Motors Milford Proving Ground near Milford, MI, the Ford Motor Company's Michigan Proving Ground near Romeo, MI, and the Transportation Research Center near East Liberty, OH.

A subset of the proposed tests was executed as part of this validation work. Five tests were conducted; each test was performed using two different countermeasure systems installed on separate test vehicles. The countermeasures included a microwave radar-based system and a laser radar-based system. Testing was done at two proving ground facilities. This report describes the testing and subsequent test data analysis that was used to study whether the tests are practical and repeatable. Other activities not associated with the execution of tests included cost and time analyses, comparison of proposed test procedures with a study of public road experiences, and investigations into whether the test requirements are inconsistent with existing test track facilities. The work conducted to date provides reason to expect that the test methodology, with minor revisions and refinements, can meet the initial set of goals.

The results and conclusions contained herein reflect the current best judgment of the Project.

7.6 Acknowledgments

The CAMP participants acknowledge the valuable cooperation of Eaton Corporation, Mitsubishi Electronics of America Inc., NovAtel Inc., Steve Lieber & Associates Inc., Transportation Research Center Inc., and VI Engineering Inc. A special thanks to Doug Fesko of VI Engineering for assisting with test execution and analysis, and Marie Cassar and Tina Burnetti-Sayer for help with the Public Road Study.

7.7 References

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APPENDIX A

APPENDIXES TO HUMAN FACTORS STUDIES (CHAPTER 3)

TABLE OF CONTENTS

List of Figures

List of Tables

A / STUDY 1

Subject Information Letter

Dear Participant,

You have been asked to participate in research on driver's braking maneuvers. As a test participant, you will drive a real car at speeds ranging from 30-60 mph. The object you will be driving behind is an "artificial" rear-end of a vehicle made of a rubber compound. This "artificial car" will be towed about 40 feet (or one and one half car lengths) behind a real car. You will be asked to make "last-second" braking judgments in order to avoid colliding with the artificial car. The passenger in the car you will be driving will be a trained General Motors Milford Proving Ground test driver. The test driver will have access to passenger-side brakes and will override your braking judgments to avoid collisions with the artificial car. Whenever the test driver overrides your braking judgments, the lead vehicle towing the artificial car will immediately accelerate. If you do collide with the lead vehicle, you should know that the artificial car is constructed of a "soft" material such that, if struck, it is designed not to cause injury to either the test participant or researchers. Furthermore, the artificial car and towing vehicle are connected with a beam that is designed to collapse and absorb the collision impact if the artificial car is struck. At the conclusion of this study you will be asked to complete a questionnaire about your experience. At no time will you be asked to perform any unsafe driving actions.

You must have a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of 2 years driving experience, be over the age of 18, pass hearing and vision tests (with correction allowed), be able to drive an automatic transmission vehicle without assistive devices or special equipment, be able to give informed consent, and not be under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair your ability to drive. In addition you must not have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or be pregnant. You must not have used alcohol, drugs, or any other substances (e.g., antihistamines) which will impair your ability to drive for a period of no less than 24 hours prior to participation.

Risks: There are some risks and discomforts to which you expose yourself in volunteering for this research. This includes the risk of an accident normally associated with driving and braking a vehicle in response to a stopped or slowing lead vehicle. Unlike in normal driving, this stopped or slowing lead vehicle will be a "soft" artificial vehicle attached to a collapsible beam (as described above), and your passenger will be a trained General Motors Milford Proving Ground test driver. This test driver will have access to passenger-side brakes and will override your "last second" braking judgments to avoid collisions with the artificial car. Whenever the test driver overrides your brakes, the (lead) tow vehicle will be instructed to immediately accelerate. If an accident does occur, the experimenters will arrange medical transportation to the Milford Proving Ground Medical facility. You will be required to undergo examination by medical personnel in the emergency room. You will be responsible for making arrangements for payment of the expenses of such treatment.

Benefits: There are no direct benefits to you from this research other than payment. However, by participating in this study, you are lending your experience as a driver to research on driver's braking behavior under certain conditions. You will not be informed as to the results of this study.

Payment: You will be paid $150 for participation in this study. The study will take about 2-2 ½ hours. Payment will be made by check at the time of participation.

Withdrawal: Participation in this study is voluntary. You may withdraw at anytime, for any reason, without penalty. Should you withdraw, you will be paid, in full, for any portion of the study you either completed or started.

Confidentiality: The data gathered in this study will be treated with anonymity. Shortly after you have participated, your name will be separated from your data and it will be given a number. Only the Principle Investigator will have access to this coding information. Your name will not appear in any reports or papers written about the project. Any videotapes of your data will be kept until they are no longer needed.

The researchers hope that you will agree to participate in this study. If you have any questions, please feel free at any time to ask the experimenter.

Once you have had your questions answered, please let the experimenter know whether you are interested in participating in this study. If you are willing to participate, the experimenter will ask you some questions to ensure that your background and experience match our research needs. If it is determined that you qualify to participate, you will be asked to read and sign an Informed Consent Form before you can actually participate in the study.

Informed Consent

I, ____________________________, agree to participate in research on driver's braking maneuvers.

1. You are being asked to volunteer to be a subject in a research project whose purpose and description are contained in the Information Letter: The purpose of this experiment is to investigate driver's braking maneuvers. As a test participant, you will drive a real car at speeds ranging from 30-60 mph. The object you will be driving behind is an "artificial" rear-end of a vehicle made of a rubber compound. This "artificial car" will be towed about 40 feet (or one and one half car lengths) behind a real car. You will be asked to make "last-second" braking judgments in order to avoid colliding with the artificial car. The passenger in the car you will be driving will be a trained General Motors Milford Proving Ground test driver. The test driver will have access to passenger-side brakes and will override your braking judgments to avoid collisions with the artificial car. Whenever the test driver overrides your braking judgments, the lead vehicle towing the artificial car will immediately accelerate. If you do collide with the lead vehicle, you should know that the artificial car is constructed of a "soft" material such that, if struck, it is designed not to cause injury to either the test participant or researchers. Furthermore, the artificial car and towing vehicle are connected with a beam that is designed to collapse and absorb the collision impact if the artificial car is struck. At the conclusion of this study you will be asked to complete a questionnaire about your experience. At no time will you be asked to perform any unsafe driving actions.

There are some risks and discomforts to which you expose yourself in volunteering for this research. These include the risk of an accident normally associated with driving and braking a vehicle in response to a stopped or slowing lead vehicle. Unlike in normal driving, this stopped or slowing lead vehicle will be a "soft" artificial vehicle attached to a collapsible beam (as described above), and your passenger will be a trained General Motors Milford Proving Ground test driver. This test driver will have access to passenger-side brakes and will override your "last second" braking judgments to avoid collisions with the artificial car. Whenever the test driver overrides your brakes, the (lead) tow vehicle will be instructed to immediately accelerate.

3. The following precautions will be taken during your drive:

The experimenter will always be present in the test vehicle and will monitor your driving. They will ask you to discontinue participation if they feel the risks are too great to continue. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe, legal manner.

The front seat experimenter will have an override brake pedal.

The vehicle is equipped with dual airbags and anti-lock brakes. Air bags inflate with great force, faster than the blink of an eye. If you're too close to an inflating air bag, it could seriously injure you. Safety belts help you keep in position before and during a crash. You should always wear your safety belt, even with air bags. You will be required to wear your lap and shoulder belt system during this test anytime the car is on the road. You should sit as far back as possible while still maintaining control of the vehicle.

The vehicle is equipped with a fire extinguisher and first-aid kit. The lead vehicle has a cellular phone.

If an accident does occur, the experimenters will arrange medical transportation to the Milford Proving Ground Medical facility. You will be required to undergo examination by medical personnel in the emergency room. You will be responsible for making arrangements for payment of the expenses of such treatment.

Trained medical personnel will be immediately accessible by phone at all times during testing.

4. The data gathered in this study will be treated with anonymity. Shortly after you have participated, your name will be separated from your data and it will be given a number. Only the Principle Investigator will have access to this coding information. Your name will not appear in any reports or papers written about the project. Any videotapes of your data will be kept until they are no longer needed. It is possible that, should you be involved in an accident during testing, the researchers will have to release your data on your driving in response to a court order.

5. You will be paid $150 for participation in this study. The study will take about 2-2 ½ hours. Payment will be made by check at the time of participation.

6. There are no direct benefits to you from this research other than payment. However, by participating in this study, you are lending your experience and expertise as a driver to investigate driver’s braking maneuvers. You will not be informed as to the results of this study.

7. By agreeing to participate, you certify that you possess a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of 2 years driving experience, are over the age of 18, have normal hearing and vision (with correction allowed), are able to drive an automatic transmission vehicle without assistive devices or special equipment, are able to give informed consent, and are not under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair your ability to drive. You also certify that you do not have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or are pregnant. Additionally, you have not used alcohol, drugs, or any other substances (e.g., antihistamines) which will impair your ability to drive for a period of no less than 24 hours prior to participation.

8. The experimenters will answer any question that you might have about this project and you should not sign this informed consent form until you are satisfied that you understand all of

the previous descriptions and conditions. You may contact the principal investigator at the following address and telephone number:

Raymond J. Kiefer, Ph.D.
CAMP
Discovery Centre
39255 Country Club Drive
Suite B-30
Farmington Hills, MI 48331
(810) 848-9595 ext. 15

9. If information becomes available which might reasonably be expected to affect my willingness to continue participating in this study, this information will be provided to me.

10. Participation in this study is voluntary. You may withdraw from this study at any time, and for any reason, without penalty. Should you withdraw, you will be paid, in full, for any portion of the study you either completed or started.

11. By signing this form you certify, to the best of your knowledge, you have no physical ailments or conditions which could either be further aggravated or adversely affected by participation in this study.

I have read and understand the scope of this research program and I have no other questions. I hereby give my consent to participate, but I understand that I may stop at anytime, if I choose to do so.

Participant:

Name:____

Address:____

Telephone:____

Signature:_______________________________________Date:___________________

Researcher:

Signature:_______________________________________Date:___________________

Test Instructions

We would like now to go over the instructions of the study. The purpose of this study is to understand how drivers brake under certain conditions. All of the testing will be conducted on a test track, which will be closed, to all other traffic during testing. The study is being conducted jointly by General Motors and Ford.

During the test, you will be asked to drive a Ford Taurus, which will be equipped with various equipment designed to measure your driving performance. When you arrive at the test track, you will be given some time to become familiar with this vehicle while the car is parked, and then while it is moving. The passenger in the car you will be driving will be a trained General Motors Milford Proving Ground test driver. This test driver will be giving you further instructions throughout the test.

During some portions of the test, you will be asked to try and maintain a certain speed, either 30, 45, or 60 mph. Please accelerate in a comfortable, quick manner to the instructed speed. During other parts of the test, you will be told to just drive at a comfortable distance behind an object. Throughout the test, the object you will be driving behind is an “artificial” rear-end of a vehicle. This lead “artificial” car will be towed about 40 feet (or one and one half car lengths) behind a “real” towing vehicle. You will be asked to make both “normal” and “last-second” braking judgments in order to avoid colliding with the lead car. When making your braking judgments, please respond as if the lead car was a real car. The lead car will sometimes be stationary (or parked) and other times be moving. When the lead car is moving, it will at times brake and come to a complete stop. The lead car is equipped with working brake lights/stop lamps. The lead car driver will brake with various braking intensities throughout the test, ranging from normal braking to relatively hard braking.

The test driver will have access to passenger-side brakes. When necessary, the test driver will override your braking judgments to avoid collisions with the lead car. Should this occur during your “last-second” braking judgments, please do not be concerned of frustrated, just do the best you can. Whenever the test driver does override the brakes, the towing vehicle ahead of the lead car will immediately accelerate. The towing vehicle will also be driven by a trained General Motors Milford Proving Ground test driver. If you do collide with the lead car, you should know that this vehicle is constructed of a “soft” material such that, if struck, it is designed not to cause injury to either the test participant or researchers. Furthermore, the lead car and the towing vehicle are connected with a beam, which is designed to collapse and absorb the collision impact if the lead car is struck. At no time will you be asked to perform any unsafe driving actions.

After the test is completed, you will be returned here. You will then be given a chance to refresh, and receive further explanation about the study. You will then be paid $150 by check and dismissed. Your total participation time will be 2-2 ½ hours.

If you now have any questions about the test, please do not hesitate to ask.

Brief Review of Test Instructions

The object you will be driving behind is an “artificial” rear-end of a car. This car is equipped with working brake lights/stop lamps. This lead car will sometimes be stationary (or parked), and other times this car will be moving.

Before each set of tests, I will be giving you instructions as to whether I want you to maintain a certain specific speed while following or approaching this lead car, or whether I want you to just drive at a comfortable distance behind this car. Please accelerate in a comfortable, quick manner to the instructed speed. I will also be giving you instructions as to when I would like you to brake in response to the slowing or stopping of the lead car. For example, during some portions of the test, I will ask you to brake in response to the lead car exactly the way you normally would during driving. During other portions of the test, I will ask you to brake at the “last second” to the slowing or stopping of the lead car. When making your braking judgments, please respond as if the lead car was a real car. The lead car driver will brake with various braking intensities throughout the test, ranging from normal braking to relatively hard braking.

Please note I will have access to passenger-side brakes. When necessary, I will override your braking judgments to avoid collisions with the lead car. You will normally here a beeping sound before I apply the brakes. This sound is my signal to apply the brakes. This signal is turned on based on the distance needed to stop our car and the current distance between our car and the lead car. If I do override your brakes during braking, please do not panic. Just continue to safely steer the car, while I brake the car to a complete stop. Also, please do not be concerned or frustrated if I do override your brakes during some tests. Just continue to do the best you can throughout the entire testing.

Whenever the beeping sound is turned on, the driver of the towing vehicle will immediately accelerate. This driver is also a trained General Motors Milford Proving Ground test driver. If you do collide with the lead car, you should know that this car is constructed of a “soft” material such that, if struck, it is designed not to cause injury to either the test participant or researchers. Furthermore, the lead car and towing vehicle are connected with a beam, which is designed to collapse and absorb the collision impact if the lead car is struck.

Detailed Description of the Surrogate Target

(Provided by Roush Industries, Inc.)

Objective - The objective was to construct a surrogate target that was capable of absorbing energy from a 20-mph impact from a 3,500-lb. vehicle and not be destroyed. The target had to look like a real vehicle when viewed from the rear. This includes functional taillights and clear vision when viewed through the rear window of the target. The target had to be transportable via common shipping methods. The target had to be able to absorb energy without deploying the airbag in either the Subject Vehicle (SV) or the Principal Other Vehicle (POV). The target had to be able to be towed by a 1997 Ford Taurus SHO (POV), which was equipped with a class 2 hitch and a 2-inch ball for towing.

Body - In order for the target to absorb energy due to a rear collision, the simulated body sheet metal was designed to deform upon impact and return to its original shape. To accomplish this, a flexible polyurethane material (Linex) was selected to mold the rear body sheet metal geometry of the target. To create the body of the target, a high temperature epoxy mold was taken directly from the rear section of a 1997 Mercury Sable.

Four coats of Linex Polyurethane were sprayed into the open cavity mold. After the initial four coats of Linex were applied, a PVC frame structure designed to support the body shell was placed into the mold. Foam padding blocks were placed between the frame and the shell prior to permanently bonding the PVC frame to the shell. The foam padding was also used to create structural reinforcing ribs across the rear deck and roof areas for added support. With the frame in place, five more coats of Linex were applied to the mold to attach the body shell to the PVC frame structure. The entire frame and shell assembly was cured in the mold for 24 hours before removal. After the Linex had fully cured, cutouts for the taillights were made and the production taillight assemblies were installed into the surrogate body shell.

A rear window was created by vacuum forming a piece of clear polycarbonate over a plaster mold. This was incorporated into the body shell using a hinge at the top center of the window and 1/8-inch rivets evenly spaced 12inches on center around the perimeter of the window. This design feature was incorporated to allow the window to break away from the body shell upon impact and return to its original position.

The body was attached to the trailer with four U-bolts and four Through bolts. The 4 U-bolts fastened the plywood header at the front of the shell body to the hoop of the trailer. Two of the Through bolts mate the plywood header to the top of the hoop. The other two Through bolts were used at the back of the trailer to locate the body laterally on the trailer. Two cables were used to help support the mass of the body shell while it is mounted on the trailer. These cables were attached at the front of the trailer, run through guides in the top of the trailer hoop, and down to eyebolts located in the rear of the PVC frame. Turnbuckles were incorporated into the cables to allow tension adjustment.

Frame - A trailer was designed to carry the simulated vehicle body shell during test maneuvers. The trailer frame was constructed using 2-inch x 2-inch x 120-inch mild steel tubing. Refer to the end of this Appendix for detail drawings of the trailer frame. A 1/2-inch thick sheet of exterior grade plywood was mounted onto the mild steel frame to establish a horizontal deck surface. A rear bumper was added to the trailer frame to prevent the SV from lodging itself underneath the trailer in the event of a rear collision. The addition of the bumper also insured that collision impact loads will act along the axis of the trailer. The bumper height was designed to be slightly less than that of the SV. The steel bumper is suspended 15 inches off the rear of the trailer by four 2.5-inch springs rated at 250 lb./inch. A sliding joint was incorporated into the trailer frame to support the mass of the bumper and insure that all bumper motion was in the axial direction. A foam absorber was molded and installed between the steel trailer bumper and the polyurethane body shell. This foam bumper was molded using a high-density 2-part expandable foam material.

The design of the trailer originally incorporated three energy absorbers between the front and rear section of the trailer frame. By incorporating the rear spring bumper, this feature was deemed unnecessary, and these parts have been deleted from the design.

Telescoping Boom - The trailer tongue assembly was designed with a telescoping boom feature that functioned as an energy absorber during a rear collision with the target. Refer to the end of this Appendix for detail drawings. The telescoping boom is designed to collapse axially upon rear impact loading. The boom consists of 4 sections of 1/4-inch thick aluminum tubing, and a small hitch section. The first, second, and fourth sections were all constructed using six-inch diameter aluminum tubing, each section being ten feet long. The first section incorporated the ball hitch receiver and attached to the second section via mating flanges. The mating flanges consist of 1/2-inch thick aluminum plates that were welded to the end of each aluminum tube section (except for the hitch section, which is made of steel). The second section incorporated a flange at the first and second section interface only. The second to third section interface did not include a flange to allow for a slip fit with the third section. The third section consists of an aluminum tube having a 5.5-inch diameter by ten feet in length. The tube diameter was machined down to 5.5 inches to allow for a slip fit between the second and fourth sections. Four 1/2-inch through holes were drilled into the third tube section to accept through bolts. The second and fourth sections were slotted horizontally along the axis of each tube to act as a guide for the through bolts located in section three. The fourth section is also open at the third and fourth section interface and is flanged at the trailer interface where it is it is bolted to the trailer. All mating flanges were bolted together with (4) 2-inch x1/2-inch bolts at each corner of the flanges. Large 1/2-inch washers were used between the bolt heads and the nuts to prevent gouging of the outer tubes as the bolts slide through the slots. Two bolts were used at either end to prevent sagging in the boom and insure that the tube will collapse and slide along the axis of the boom during an impact.

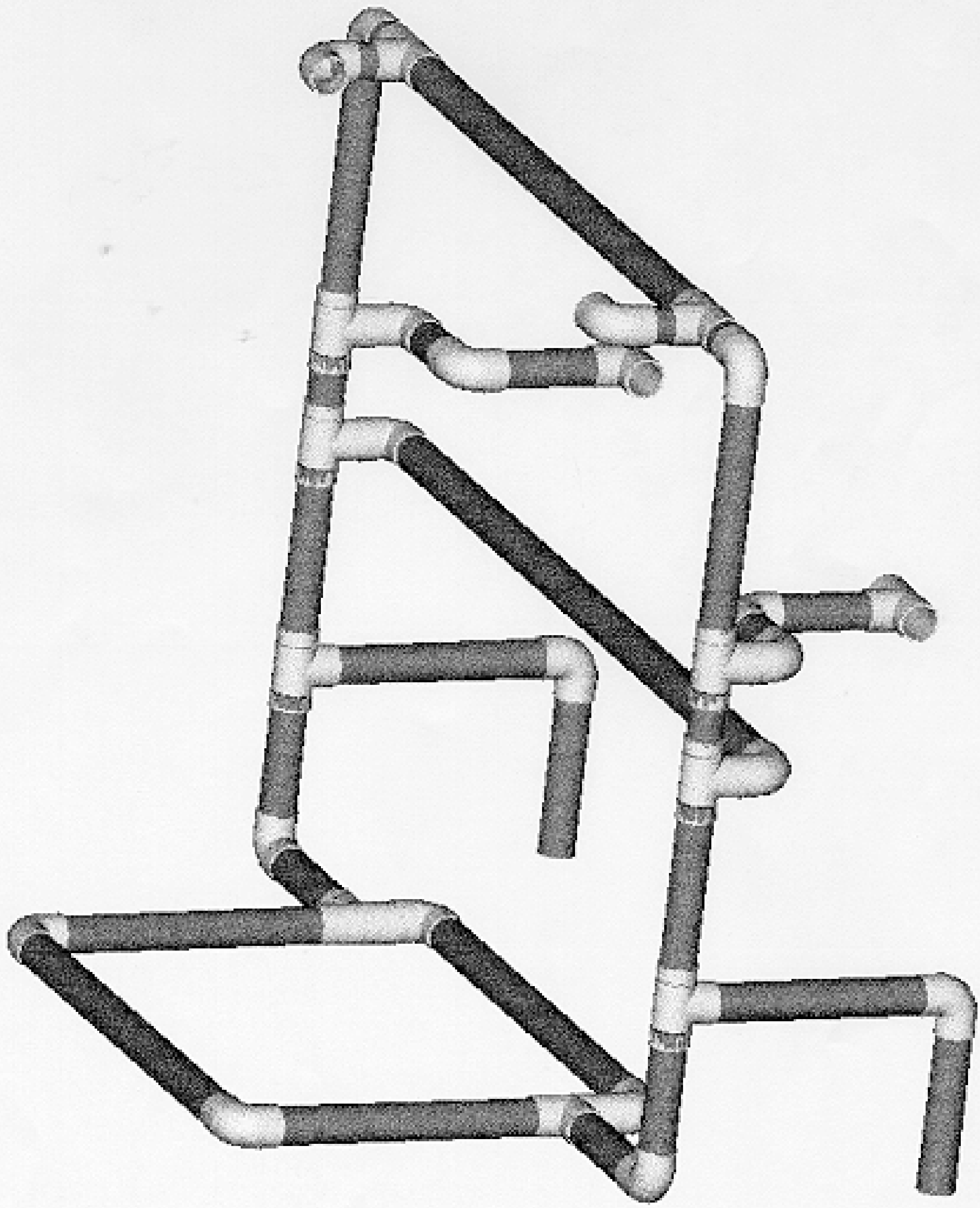
Brakes - An electric trailer braking system was used to improve braking stability and improve safety during test maneuvers. The trailer brakes are primarily activated directly from the brakes of the POV but can also be activated independently through a manual override system. In the linked mode, the braking system utilizes a sensor that proportions the braking force of the trailer with that of the POV. This sensor is adjustable to allow brake proportioning between the trailer and the tow vehicle. This was used to calibrate the braking system to the weight of the Surrogate Target assembly. In the independent mode, the trailer brakes can be activated separately from the

POV via a manual switch. This would allow the brakes of the trailer to be activated independently without activating the brakes in the POV.

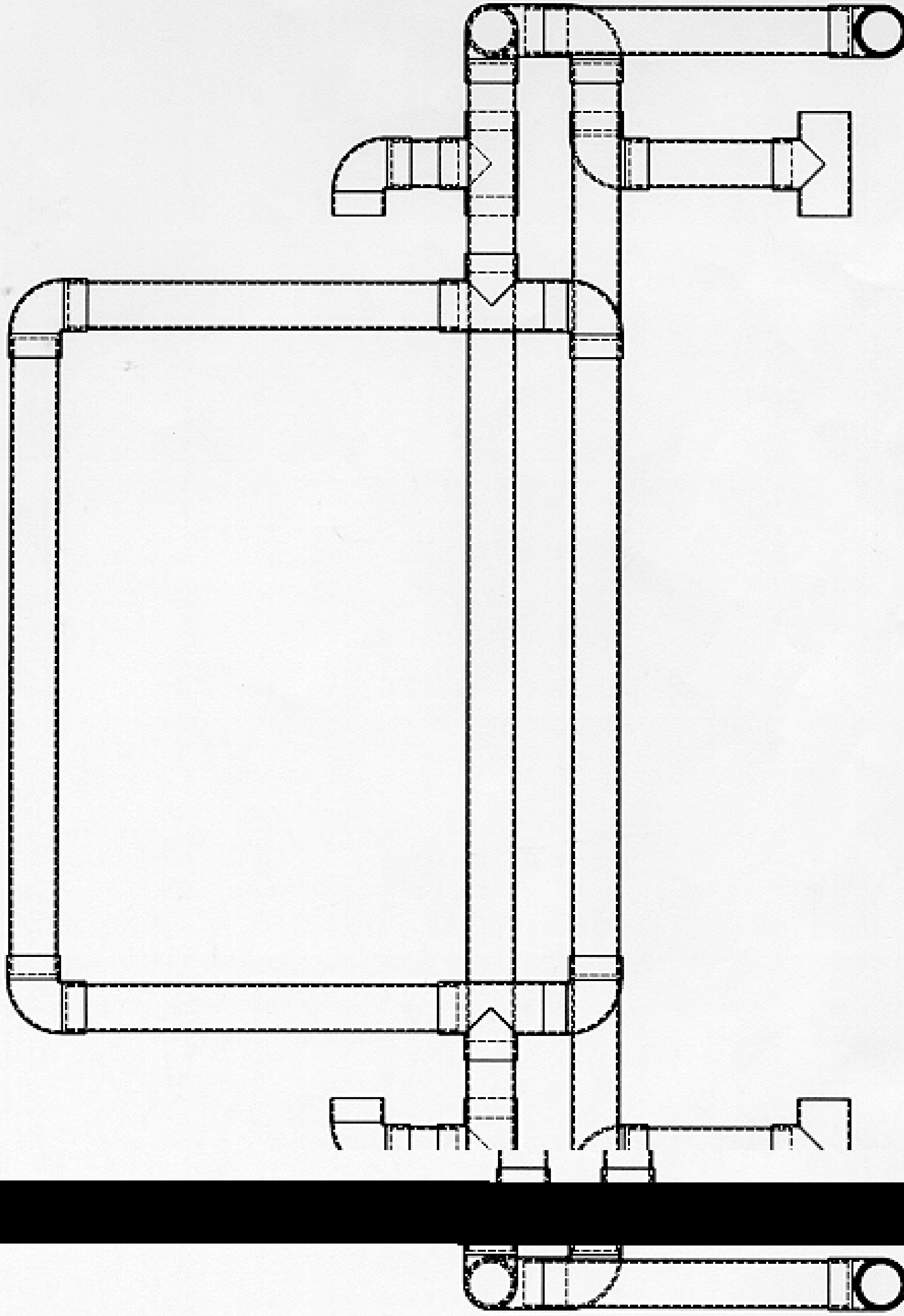
Electrical - All electrical wiring was custom fabricated to be modular in design. Quick disconnect, all weather connectors were used to ease installation and removal of the body. The production taillights used the production wiring sub-assemblies, which were easily disconnected from the main harness of the trailer. Quick disconnect, all weather connectors were also used in the wiring harness at the end of each boom section in case the boom needed to be shortened or lengthened. The wiring harness was covered with a protective shield of convolute tubing and secured to the trailer. All wiring was tested to insure all lights functioned properly. All wiring required to support the trailer brakes, taillights and high-mounted stoplight was constructed and fastened to the deck of the trailer. Quick-disconnect connectors were used to ease installation and removal of the body. Quick-disconnect connectors were used in the wiring harness at the end of each section of the boom. Wiring was made modular in case the boom was to be shortened by sections.

Component List

(1) 55 gallon drum Linex part B
(1) 55 gallon drum Linex part A
(1) Right taillight – part # F6DZ13404B
(1) Left taillight – part #FF6DZ13405B
(1) Right reflector – part #F7DZ13A565AB
(1) Left reflector – part #F7DZ13A565AA
(1) High mount third brake light – part #F6DZ13A613AD
(2) Stop signal sockets – part #F6DZ13410B
(2) Turn signal sockets – part #F6DZ13411A
(4) Brake & turn bulbs – part #F5DZ13466B
(2) Side marker bulbs – part #CZAZ13466C
(2) High mount third brake light bulb – part #D7TZ13466A
(1) 3,500-lb. Class 2 hitch
(48 feet) 2" x 2" .120" steel tubing
(24 feet) 1" x 1" x .090" steel tubing
(12 feet) 1" x 2" x .090" steel tubing
(1) 2' x 4' .25' steel plate
(30) feet 6" x .25 6061-T6 aluminum pipe
(10 feet) 5.5" x .25 6061-T6 aluminum pipe
(1) 2' x 4' x .50 aluminum plate
(36 feet) 2.5" PVC pipe
(18) 90-degree PVC elbow fittings
(12) PVC "T" fittings
(1) 2" 3,500-lb. trailer hitch coupler
(2) Light duty ratcheting tie downs
(1) Set 7" brakes
(2) 7" brake drums
(2) Brake flanges
(1) Brake controller
(1) 15 amp inline fuse
(1) Circuit breaker
(2) 5.30 x 12 B tires and rims
(1) 2,000-lb. axle assembly
(1) Sheet ½" CDX plywood
(4) Eiback 250 lb./in. 2.55" x 14" coil springs – part #1400-250-0250
(4) 7" x ½" x 13 grade 8 bolts
(16) 2" x ½" x 13 grade 8 bolts
(20) ½" x 12 grade 8 bolts
(40) ½" flat washers
(1) 6" x 1" hinge
(1) Sheet 1/8" polycarbonate
(2) ¼" turnbuckles
(25 feet) ¼ steel cable
(1) Gallon foam, part A
(1) Gallon foam, part B

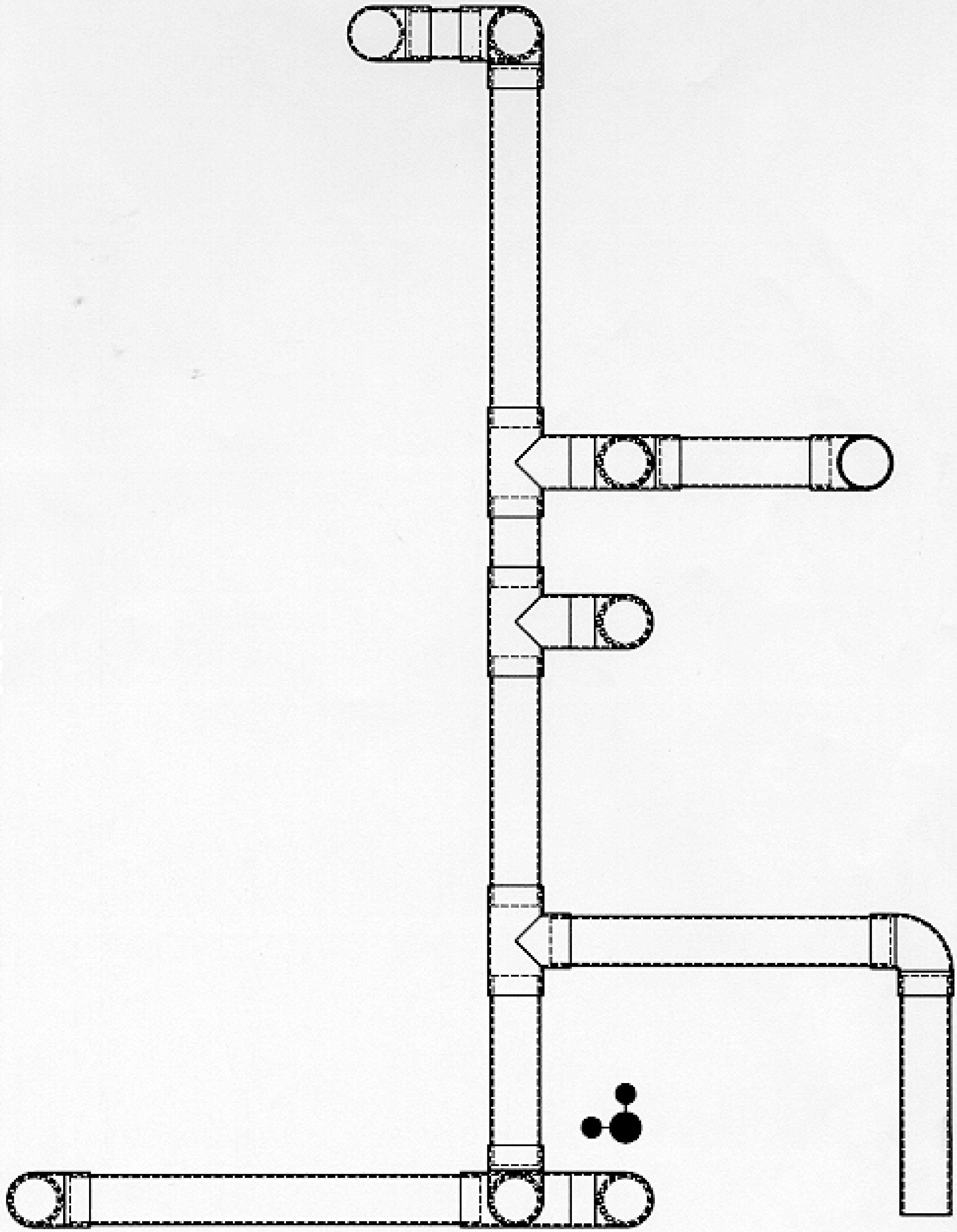


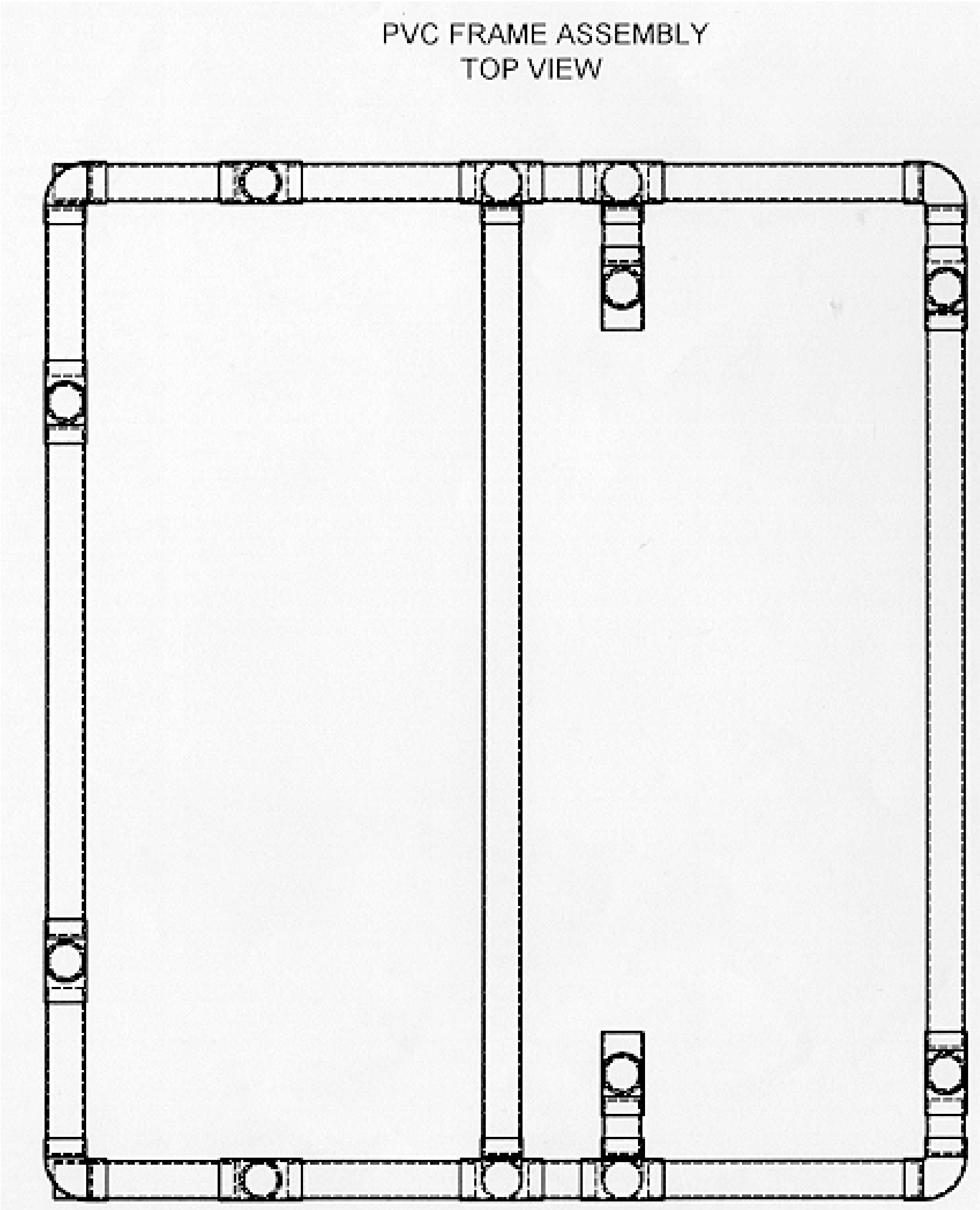
PVC FRAME ASSEMBLY

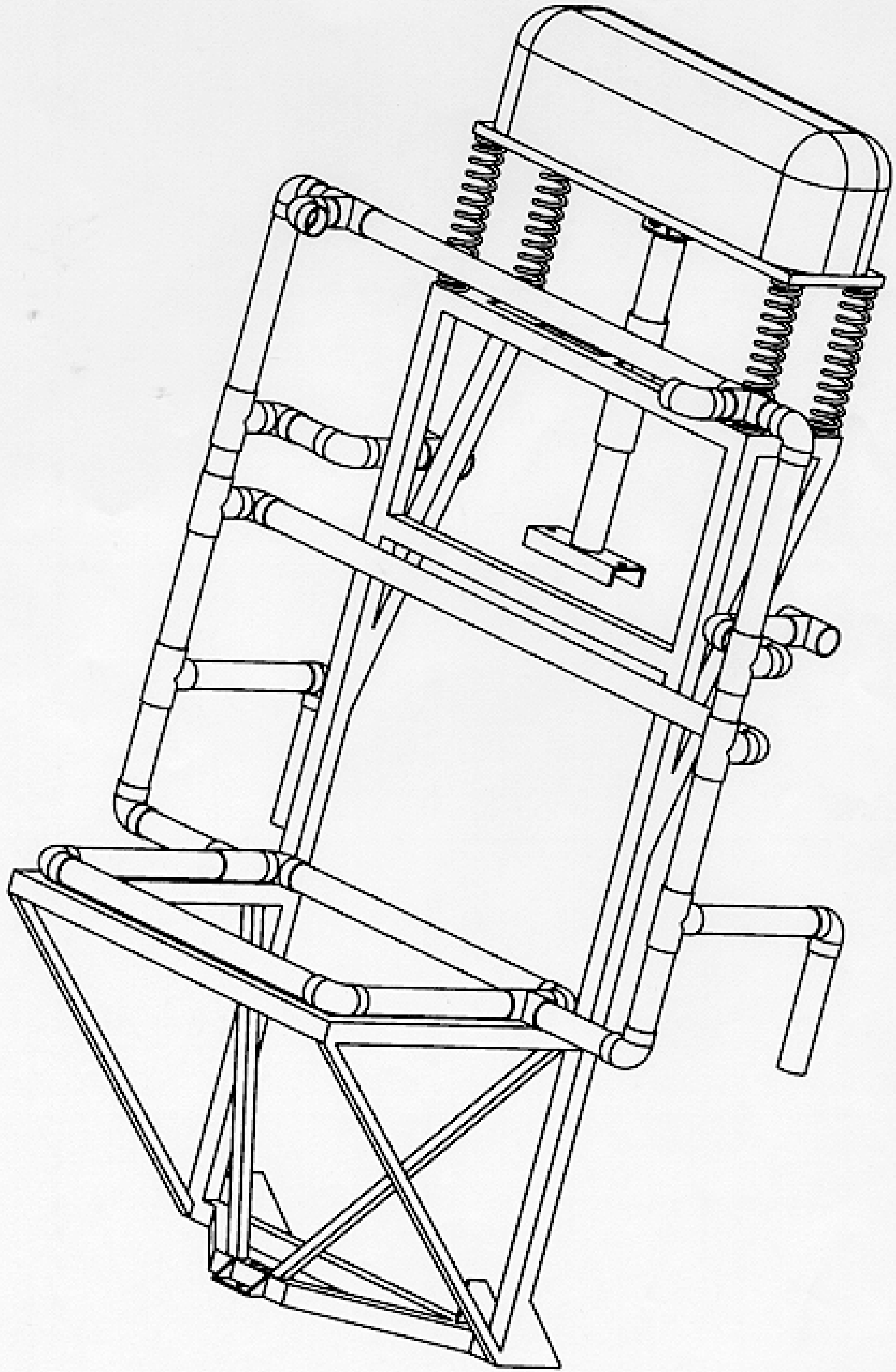


PVC FRAME ASSEMBLY
FRONT VIEW

PVC FRAME ASSEMBLY
SIDE VIEW

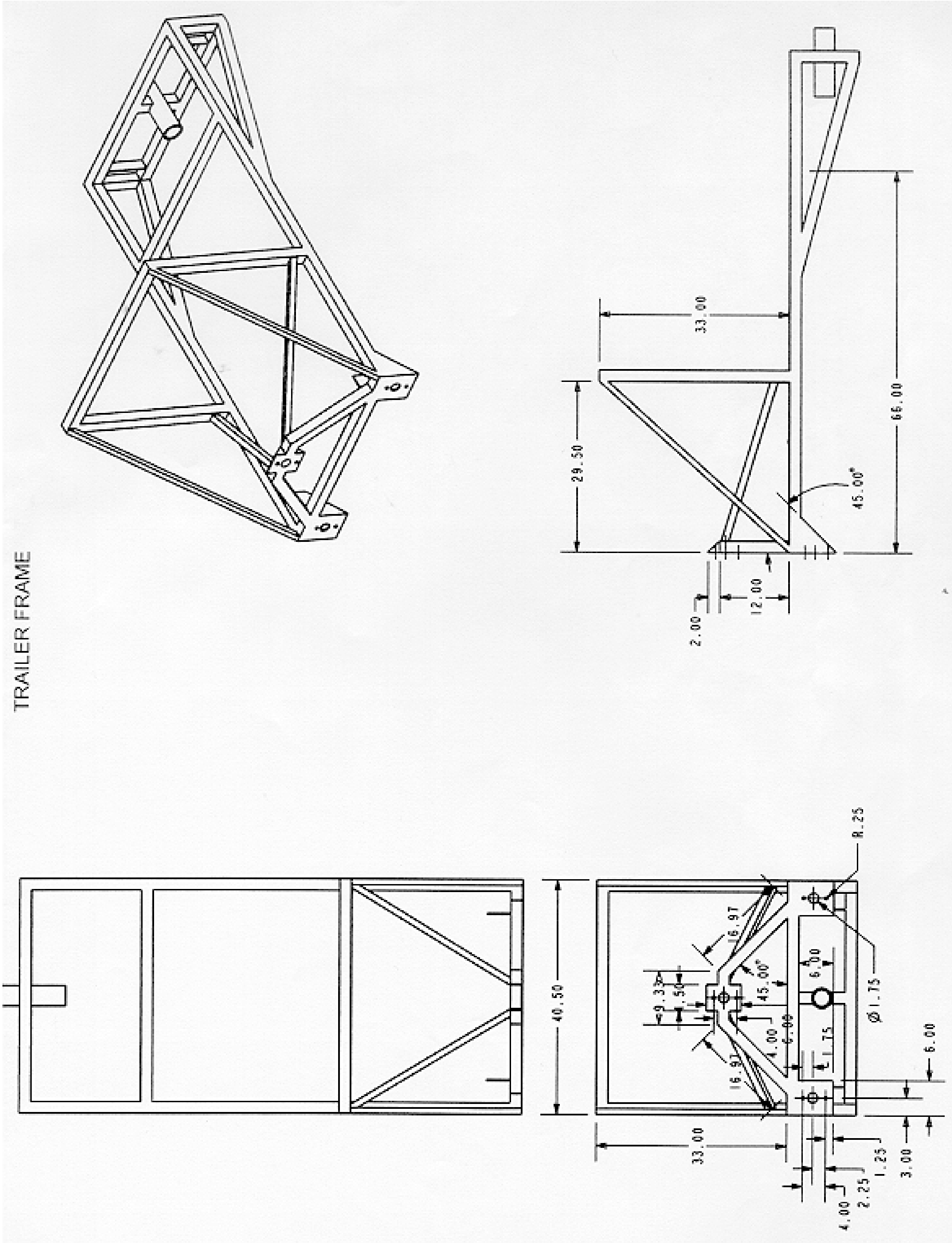


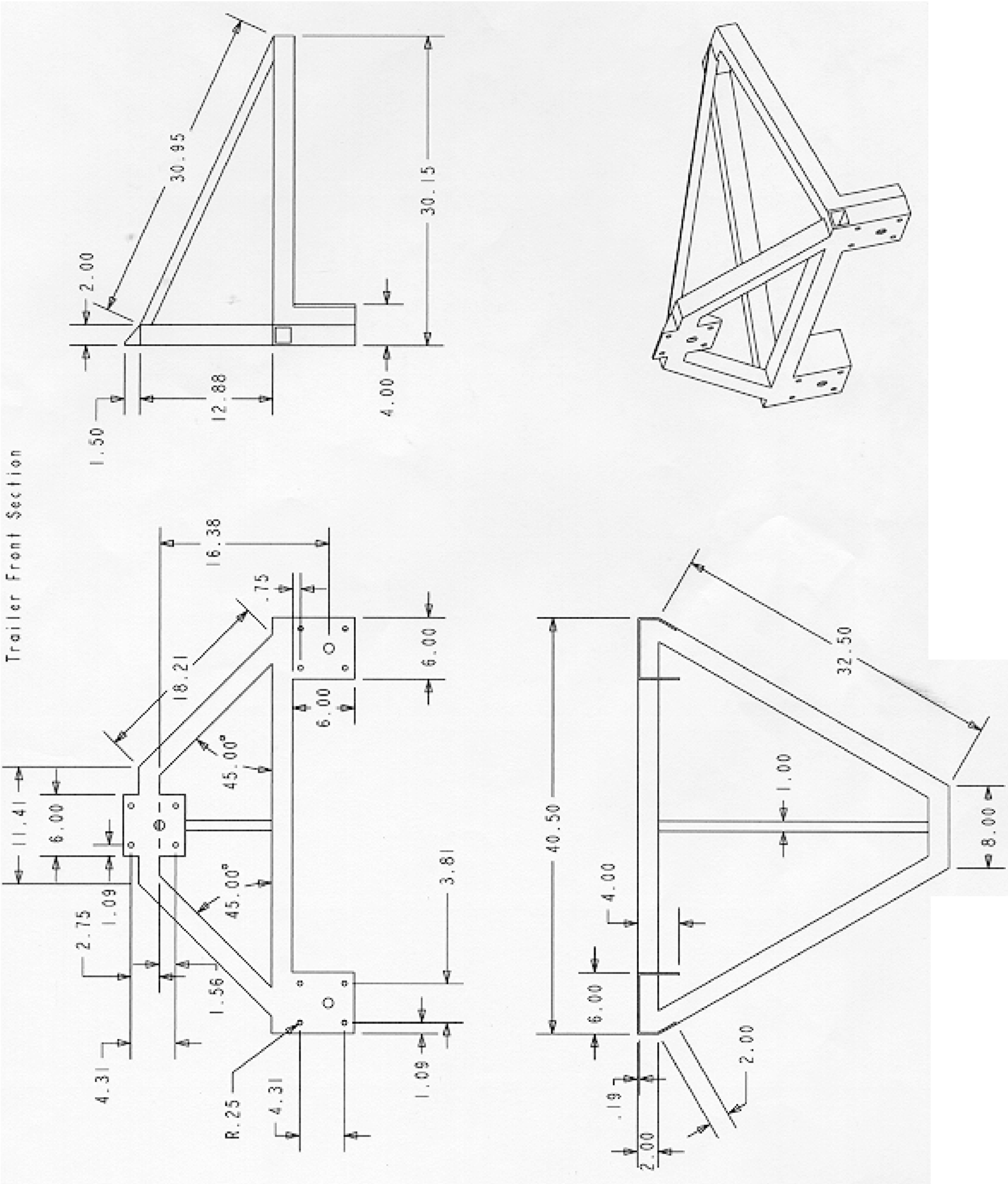

PVC FRAME ASSEMBLY
TOP VIEW



TRAILER ASSEMBLY

TRAILER FRAME




Trailer Front Section
30.95
2.00
30.15
12.88
1.50
4.00
16.38
.75
18.21
6.00
6.00
11.41
6.00
45.00°
45.00°
1.09
2.75
1.56
3.81
4.31
R.25
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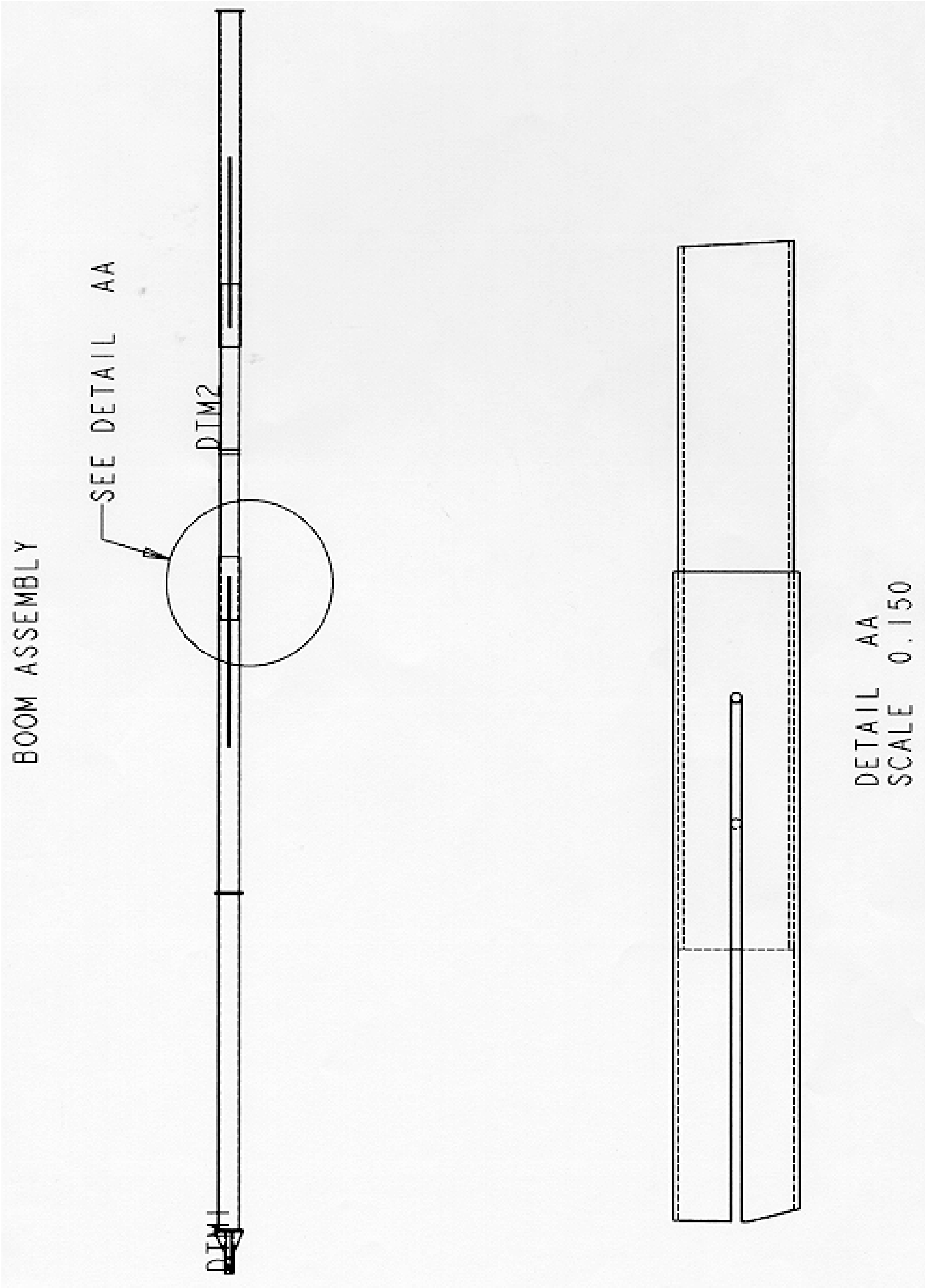
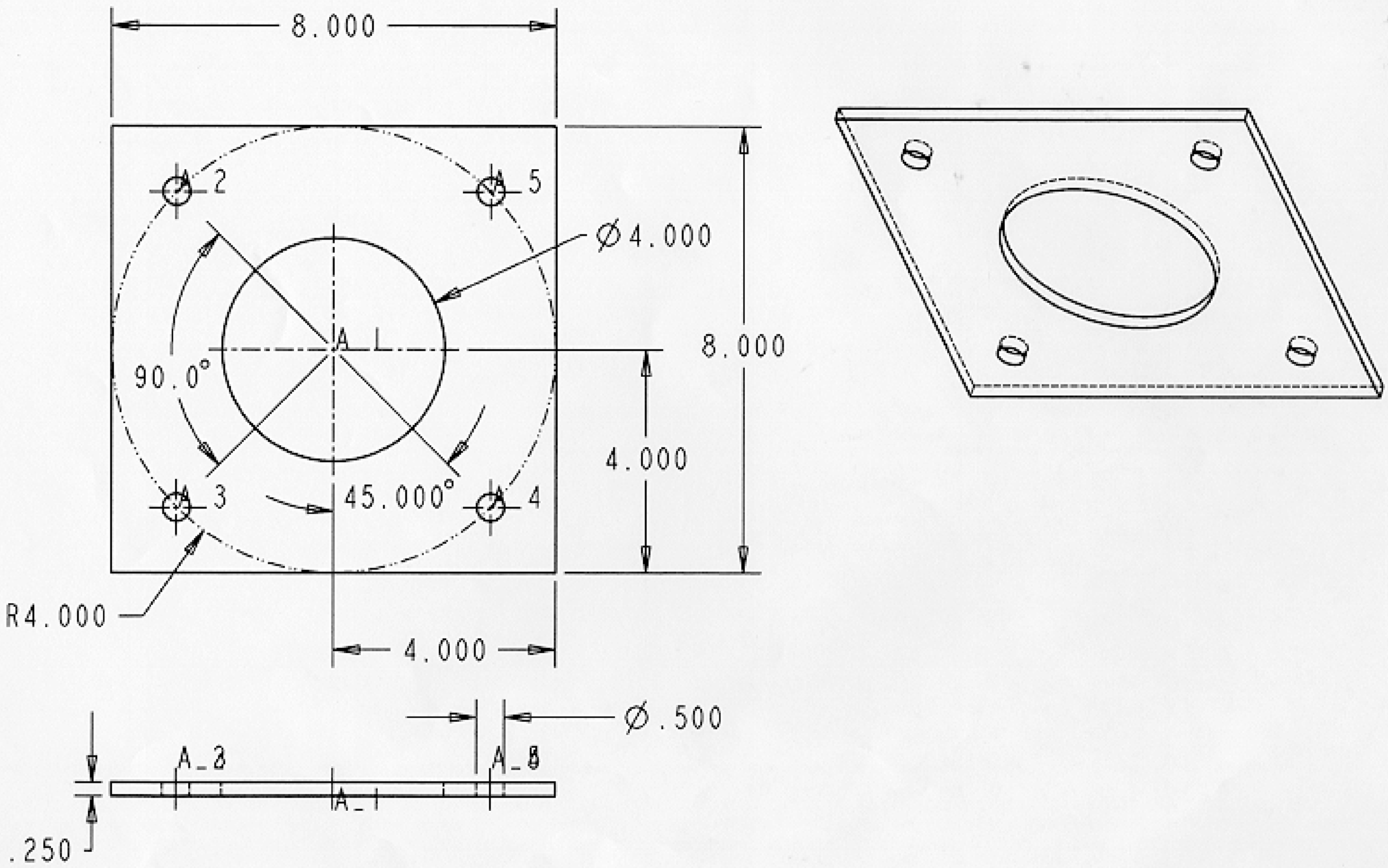
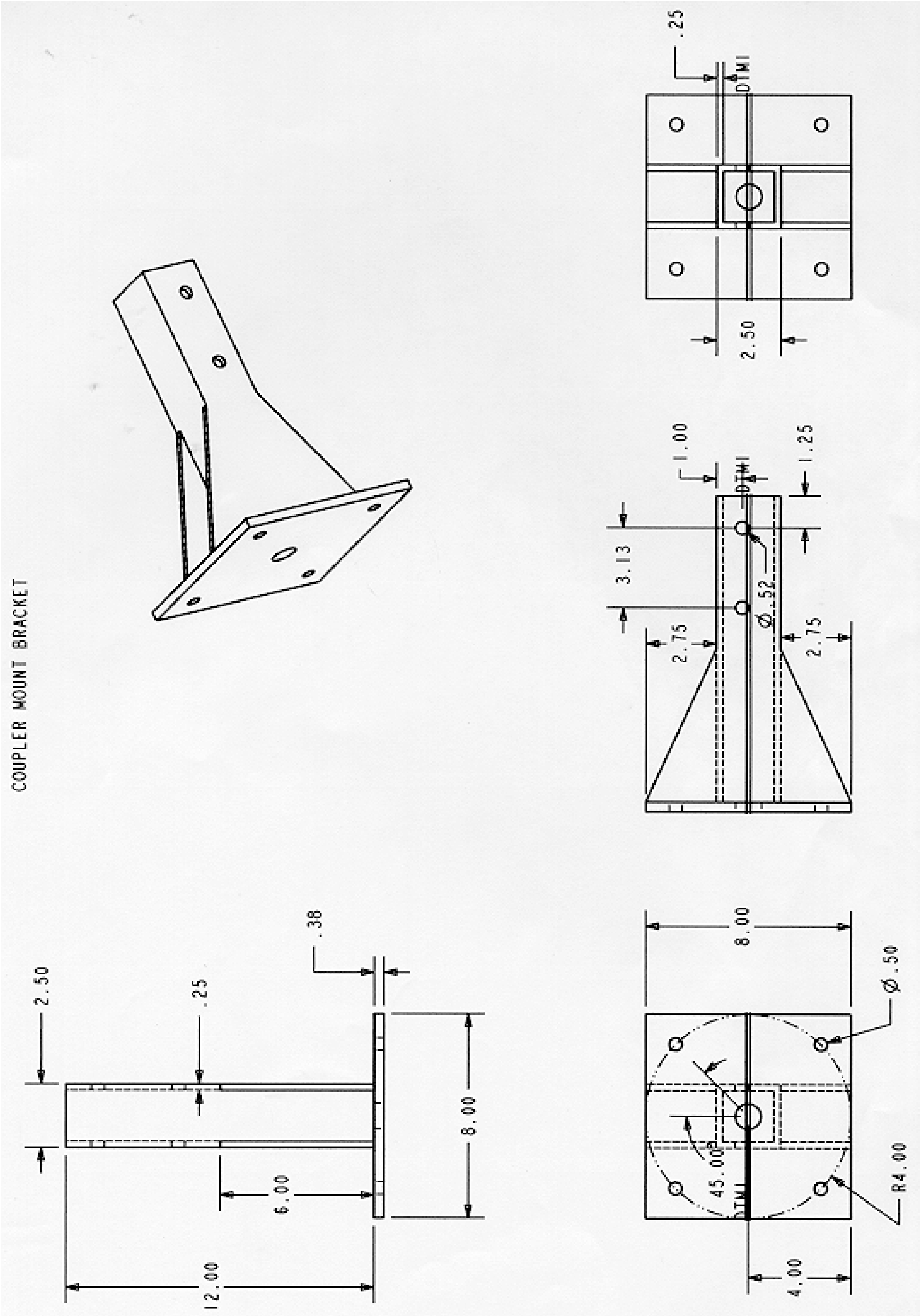
.19
2.00
2.00


BOOM ASSEMBLY
SEE DETAIL AA
DTM2
DTM1
DETAIL AA
SCALE 0.150



Aluminum Flange for Boom Sections


COUPLER MOUNT BRACKET
2.50
.25
.38
6.00
8.00
12.00
8.00
Ø.50
45.00
R4.00
4.00
DTM1
3.13
1.00
1.25
Ø.52
2.75
2.75
.25
2.50

A1 / STUDY 2 - SUBJECT INFORMATION LETTER

Dear Participant,

Last year (between mid-August and mid-October) you participated in a research project that was conducted at the Milford Proving Grounds in Milford, Michigan. That project examined driver's braking maneuvers, and is one of a continuing program of research being conducted by Ford and GM. The purpose of this research program is to understand how to properly design a feature for cars which could reduce the frequency and severity of rear-end accidents. Such a feature would have the potential to greatly improve traffic safety. In the United States, rear-end accidents account for about 25% of all accidents and 5% of all fatal accidents. The previous study in which you participated was aimed at understanding driver's braking judgments without a crash avoidance feature. The data from this study provided us with an essential building block for understanding how to design a crash avoidance feature for rear-end accidents.

The current project is a follow-up to this earlier project, and is similar in many respects. As a test participant, you will again be driving a real car at speeds ranging from 30-60 mph. The object you will be driving behind is an "artificial" rear-end of a vehicle identical to the "artificial car" you previously experienced. This "artificial car" will be towed about 40 feet (or one and one half car lengths) behind a real car. You will be asked to brake in response to rear-end crash alerts in order to avoid colliding with the artificial car. We will be testing several different types of crash alerts.

The passenger in the car you will be driving will again be a trained General Motors Milford Proving Ground test driver. As before, the test driver will have access to passenger-side brakes and will override your braking to avoid collisions with the artificial car. If you do collide with the lead vehicle, you should know that the artificial car is constructed of a material such that, if struck, it is designed not to cause injury to either the test participant or researchers. Furthermore, the artificial car and towing vehicle are connected with a beam, which is designed to collapse and absorb the collision impact if the artificial car is struck. During this study you will be asked to complete a questionnaire about your experience. At no time will you be asked to perform any unsafe driving actions.

You must have a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of two years driving experience, be 20 years of age or older, have normal hearing and vision (with correction allowed), be able to drive an automatic transmission vehicle without assistive devices or special equipment, be able to give informed consent, and not be under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair your ability to drive.

In addition you must not have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or be pregnant.

You must not have used alcohol, drugs, or any other substances (e.g., antihistamines) which will impair your ability to drive for a period of no less than 24 hours prior to participation.

Risks: There are some risks and discomforts to which you expose yourself in volunteering for this research. This includes the risk of an accident normally associated with driving and braking a vehicle in response to a stopped or slowing lead vehicle. Unlike in normal driving, this stopped or slowing lead vehicle will be an artificial vehicle attached to a collapsible beam, and your passenger will be a trained General Motors Milford Proving Ground test driver. This test driver will have access to passenger-side brakes and will override your braking in order to avoid collisions with the artificial car. If an accident does occur, the experimenters will arrange medical transportation to the Milford Proving Ground Medical facility. You will be required to undergo examination by medical personnel there. You will be responsible for making arrangements for payment of subsequent treatment.

Benefits: There are no direct benefits to you from this research other than compensation for your time and effort. However, by participating in this study, you are lending your experience as a driver to research aimed at understanding how to properly design a feature for cars which could reduce the frequency and severity of rear-end accidents. You will not be informed as to the results of this study.

Payment: You will be paid $150 for participation in this study. The study will take about 2-2 ½ hours. Payment will be made by check at the time of participation.

Withdrawal: Participation in this study is voluntary. You may withdraw at anytime, for any reason, without penalty. Should you withdraw, you will still be paid in full.

Confidentiality: The data gathered in this study will be treated with anonymity. Shortly after you have participated, your name will be separated from your data and it will be given a number. Only the Principle Investigator will have access to this coding information. Your name will not appear in any reports or papers written about the project. Any videotapes of the data, which will include video of the your head and face, will be kept until they are no longer needed. Confidentiality of this video information will be protected.

The researchers hope that you will agree to participate in this study. If you have any questions, please feel free at any time to ask the experimenter.

Once you have had your questions answered, please let the experimenter know whether you are interested in participating in this study. If you are willing to participate, the experimenter will ask you some questions to ensure that your background and experience match our research needs. If it is determined that you qualify to participate, you will be asked to read and sign an Informed Consent Form before you can actually participate in the study.

A2 / STUDY 2 - INFORMED CONSENT STATEMENT

I, ____________________________, agree to participate in research aimed at understanding how to properly design a feature for cars which could reduce the frequency and severity of rear-end accidents.

1. You are being asked to volunteer to be a subject in a research project whose purpose and description are contained in the Information Letter. The purpose of this research program is to understand how to properly design a feature for cars which could reduce the frequency and severity of rear-end accidents. As a test participant, you will drive a real car at speeds ranging from 30-60 mph. The object you will be driving behind is an “artificial” rear-end of a vehicle. This “artificial car” will be towed about 40 feet (or one and one half car lengths) behind a real car. You will be asked to brake in response to rear-end crash alerts in order to avoid colliding with the artificial car. The passenger in the car you will be driving will be a trained General Motors Milford Proving Ground test driver. The test driver will have access to passenger-side brakes and will override your braking judgments to avoid collisions with the artificial car. If you do collide with the lead vehicle, you should know that the artificial car is constructed of a material such that, if struck, it is designed not to cause injury to either the test participant or researchers. Furthermore, the artificial car and towing vehicle are connected with a beam, which is designed to collapse and absorb the collision impact if the artificial car is struck. During the test you will be asked to complete a questionnaire about your experience. At no time will you be asked to perform any unsafe driving actions.

There are some risks and discomforts to which you expose yourself in volunteering for this research. These include the risk of an accident normally associated with driving and braking a vehicle in response to a stopped or slowing lead vehicle. Unlike in normal driving, this stopped or slowing lead vehicle will be an artificial vehicle attached to a collapsible beam (as described above), and your passenger will be a trained General Motors Milford Proving Ground test driver. This test driver will have access to passenger-side brakes and will override your braking in order to avoid collisions with the artificial car.

3. The following precautions will be taken during your drive:

The experimenter will always be present in the test vehicle and will monitor your driving. They will ask you to discontinue participation if they feel the risks are too great to continue. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe, legal manner.

The front seat experimenter will have an override brake pedal.

The vehicle is equipped with a driver-side airbag and anti-lock brakes. Air bags inflate with great force, faster than the blink of an eye. If you’re too close to an inflating air bag, it could seriously injure you. Safety belts help you keep in position before and during a crash. You should always wear your safety belt, even with air bags. You will be required to wear your lap and shoulder belt system during this test anytime the car is moving. You should sit as far back as possible while still maintaining control of the vehicle.

The vehicle is equipped with a fire extinguisher and first-aid kit. The lead vehicle has a cellular phone.

If an accident does occur, the experimenters will arrange medical transportation to the Milford Proving Ground Medical facility. You will be required to undergo examination by medical personnel in the emergency room. You will be responsible for making arrangements for payment of the expenses of such treatment.

Trained medical personnel will be immediately accessible by phone at all times during testing.

4. The data gathered in this study will be treated with anonymity. Shortly after you have participated, your name will be separated from your data and it will be given a number. Only the Principle Investigator will have access to this coding information. Your name will not appear in any reports or papers written about the project. Any videotapes of the data, which will include video of your head and face, will be kept until they are no longer needed. Confidentiality of this video information will be protected.

It is possible that, should you be involved in an accident during testing, that the researchers will have to release your data on your driving in response to a court order.

5. You will be paid $150 for participation in this study. The study will take about 2-2 ½ hours. Payment will be made by check at the time of participation.

6. There are no direct benefits to you from this research other than payment. However, by participating in this study, you are lending your experience as a driver to research aimed at understanding how to properly design a feature for cars which could reduce the frequency and severity of rear-end accidents. You will not be informed as to the results of this study.

7. By agreeing to participate, you certify that you possess a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of 2 years driving experience, be 20 years of age or older, have normal hearing and vision (with correction allowed), are able to drive an automatic transmission vehicle without assistive devices or special equipment, are able to give informed consent and are not under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair your ability to drive. You also certify that you do not have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or are pregnant. Additionally, you have not used alcohol, drugs, or any other substances (e.g., antihistamines) which will impair your ability to drive for a period of no less than 24 hours prior to participation.

8. The experimenters will answer any question that you might have about this project and you should not sign this informed consent form until you are satisfied that you understand all of

the previous descriptions and conditions. You may contact the principal investigator at the following address and telephone number:

Raymond J. Kiefer, Ph.D.

CAMP

Discovery Centre

39255 Country Club Drive

Suite B-30

Farmington Hills, MI 48331

(248) 848-9595 ext. 15

9. If information becomes available which might reasonably be expected to affect your willingness to continue participating in this study, this information will be provided to me.

10. Participation in this study is voluntary. You may withdraw from this study at any time, and for any reason, without penalty. Should you withdraw, you will still be paid in full.

11. By signing this form you certify, to the best of your knowledge, you have no physical ailments or conditions which could either be further aggravated or adversely affected by participation in this study.

I have read and understand the scope of this research program and I have no other questions at this time. I understand that I am free to ask questions at any time. I hereby give my consent to participate, but I understand that I may stop at anytime, if I choose to do so.

Participant:

Name:____

Address:____

Telephone:____

Signature:___________________________________Date:_________________

Researcher:

Signature:___________________________________Date:_________________

A3 / STUDY 2 - TEST INSTRUCTIONS

The purpose of this study is to understand both when and how to present crash warning information to drivers. All of the testing will be conducted on a test track, which is closed to all other traffic during testing. The study is being conducted jointly by General Motors and Ford.

During the test, you will asked to drive a Ford Taurus, which has been equipped with various devices designed to measure your driving performance. Once you get into the vehicle, you will be given some time to become familiar with it. The passengers in the car with you while you're driving will be a trained General Motors Milford Proving Ground test driver and also myself. Both the test driver and myself will be giving you further instructions throughout the test.

Throughout the test, you will be experiencing crash alerts while approaching a stationary artificial car. You will be asked to approach the artificial car at either 30 or 60 mph. Please accelerate in a comfortable, quick manner to reach the speed instructed.

Your task is to keep your foot on the accelerator and maintain a steady speed until the crash alert occurs. When the crash alert occurs, you should brake immediately by quickly moving your foot from the accelerator to the brake. Please brake the car to a complete stop such that you do not collide with the artificial car. Please brake the car in any way you are comfortable and that you feel is appropriate to avoid colliding with the artificial car. Once again, it is extremely important that you keep your foot on the accelerator and maintain a steady speed until the crash alert occurs.

Because you will be expecting the crash alert to occur, your RT to the crash alert will be faster than what it would be under normal driving conditions. Because of these faster RTs, we have shortened the warning distances so that you can experience when you might begin braking if your vehicle had a crash alert system (show illustration). Each time you complete a braking event, I will ask you two questions about the alert. One question is about the timing of the alert and the other is about the urgency level of the alert. When answering both of these questions, please rate the timing and urgency level of the alert based on your own experience during the test as a highly alert driver that is expecting the alert to occur. Please keep in mind that you will be experiencing when you might begin braking if your vehicle had a crash alert system (show illustration).

The test driver in the car with you will have access to passenger-side brakes. When necessary, the test driver will override your braking to avoid collisions with the artificial car. But if that should happen, please do not become concerned or frustrated, just do the best you can. If you do collide with the artificial car, you should know that it is constructed of a "soft" material such that, if struck, it is designed not to cause injury to either you or the test drivers. At no time will you be asked to perform any unsafe driving actions.

After the test is completed, you will be returned here. You will then be given a chance to refresh, and receive further explanation about the study. You will then be paid $150 by check and dismissed. Your total participation time will be 2-2 ½ hours.

If you now have any questions about the test, please do not hesitate to ask.

A4 / STUDY 2 - ALERT MODALITY APPROPRIATENESS QUESTIONNAIRE (EXCERPTS)

Assume that the crash alerts you just experienced are going to be implemented in a vehicle. Use the rating scale below to respond to each question about the warning. Mark the number from the scale that corresponds to your response in the space provided at the beginning of each question.

1	2	3	4	5
Terrible	Poor	Fair	Good	Excellent

USED FOR BOTH HHDD AND HUD VISUAL ALERTS

________ How would you rate the intensity or brightness of this display?
________ How would you rate the size of this display?
________ How would you rate the color of this display?
________ How would your rate the location of this display?

USED FOR BOTH SPEECH AND NON-SPEECH AUDITORY ALERTS

________ How would you rate the loudness of this warning?

1	2	3	4	5	6	7
Extremely Soft	Moderately Soft	Slightly Soft	Just Right	Slightly Loud	Moderately Loud	Extremely Loud

________ How would you rate the duration or length of this warning?

1	2	3	4	5	6	7
Extremely Short	Moderately Short	Slightly Short	Just Right	Slightly Long	Moderately Long	Extremely Long

USED FOR THE BRAKE PULSE ALERT

________ How would you rate the strength of the vehicle jerk that occurred during this warning?

1	2	3	4	5	6	7
Extremely Weak	Moderately Weak	Slightly Weak	Just Right	Slightly Strong	Moderately Strong	Extremely Strong

________ How would you rate the duration or length of this warning?

1	2	3	4	5	6	7
Extremely Short	Moderately Short	Slightly Short	Just Right	Slightly Long	Moderately Long	Extremely Long

A5 / STUDY 2 – CRASH ALERT APPROPRIATENESS QUESTIONNAIRE

Please indicate the extent to which you agree with the following statements for each method of presenting crash alert information you experienced in the study. Please consider both the conditions when you expected the alert and when the alert was a surprise event.
Use the numbering on the scale below to make your responses. Place your response in the appropriate column below.

1	2	3	4	5	6	7
Strongly Disagree	**Moderately Disagree**	**Perhaps Disagree**	**Neutral**	**Perhaps Agree**	**Moderately Agree**	**Strongly Agree**

	Head-Up Display & Tone	High Head Down & Tone	High Head Down & Speech	High Head Down & Pulse
1. This is a good method for presenting crash alerts to drivers.				
2. This method would be clearly noticeable in the car.				
3. This method would NOT be confused with other events happening either inside or outside the car.				
4. This method would get my attention immediately if I was distracted and not concentrating on the driving task.				
5. This method would NOT startle me, that is, cause me to blink, jump, or make a rapid reflex-like movement.				
6. This method would NOT interfere with my ability to make a quick and accurate decision about the safest driving action to				
7. This method would NOT interfere with my ability to perform a quick an accurate emergency driving action.				
8. This method would NOT annoy me if the alert came on once a week in a situation where no driving action was required.				
9. This method would NOT annoy me if the alert came on once a day in a situation where no driving action was required.				
10. This method would NOT appear out of place in a car or truck.				
11. This method would clearly tell me that I am in danger and need to react immediately.				
12. This method of presenting crash alert information has great potential for preventing me from getting in a rear-end accident.				
13. This method of presenting crash alert information would get my attention without being overly annoying.				
14. If cost was not an issue, I would be likely to purchase this type of crash alert feature when I purchased a vehicle.				

A6 / STUDY 2 - BUILD AN INTERFACE QUESTIONNAIRE

In this study, you were instructed to pay attention to the alerts. However, in normal driving situations, the crash alert would probably occur when drivers are not concentrating on the driving task.

If you could design your own crash alert system, which <u>alert or combination of alerts</u> used in this study do you think would be most effective for getting your attention and prompting you to respond appropriately in dangerous driving situations?

Below is a list of the different types of crash alerts you experienced. Please check the crash alert(s) you would use to design your own system.

- ☐ Head-Up Display (symbol projected onto windshield)
- ☐ High Head-Down (symbol illuminated on dashboard display)
- ☐ Tone Warning
- ☐ Speech Warning
- ☐ Brake Pulse

Now instead of the single alerts you experienced today, assume that the alert had two stages -- a cautionary stage and an imminent stage. The first-stage cautionary alert would probably come on just about a second earlier than the one-stage alert. Then, if the driver does not correct the dangerous situation, the cautionary alert would transition into the second-stage imminent alert.

The difference between one- and two-stage alerts is that a more aggressive driving maneuver will probably be required when a one-stage alert comes on than when a cautionary alert of the two-stage alert comes on. However, if the second-stage imminent alert comes on, a very aggressive driving maneuver will probably be required. In addition, because a cautionary alert is more conservative in its timing, the alert will probably come on more often possibly making it annoying to some drivers.

We would like your help designing a two-stage crash alert system. Please check the crash alert(s) below that you think would be most effective as a first-stage cautionary alert and a second-stage imminent alert. You can choose any combination of alerts for either stage that you wish, however, the first and second stages need to be distinguishable.

CAUTIONARY ALERT (First stage)

- ☐ Head-Up Display
- ☐ Tone Warning
- ☐ High Head-Down
- ☐ Speech Warning
- ☐ Brake Pulse

IMMINENT ALERT (Second stage)

- ☐ Head-Up Display
- ☐ Tone Warning
- ☐ High Head-Down
- ☐ Speech Warning
- ☐ Brake Pulse

A7 / STUDY 2 - NAME THE SYSTEM QUESTIONNAIRE

Now that you have some idea about what a warning system would be like, we would your opinion about what to name it. The name should clearly identify the system for users.

The proposed system would function very much like the system you experienced in the study. That is, when a driver approaches a slower or stopped vehicle, the system would alert the driver to the dangerous situation.

What do you think would be a good name for this system?

____

(The following was shown on the following page of the questionnaire)

Listed below are other names that have been proposed for the new warning system. Please choose three names that you think would be good choices.

Number your choices 1 (best), 2 (second best), and 3 (third best).

______ Forward Collision Warning System

______ Forward Crash Warning System

______ Forward Accident Warning System

______ Rear-end Collision Warning System

______ Rear-end Crash Warning System

______ Rear-end Accident Warning System

______ Front-end Collision Warning System

______ Front-end Crash Warning System

______ Front-end Accident Warning System

A8 / STUDY 3 - SUBJECT INFORMATION LETTER

Dear Participant,

You are being asked to participate in research which will examine the distance a driver normally follows the vehicle ahead under a variety of situations. The data from this study will provide us with an essential building block for understanding how to design a feature for cars that would automatically adjust the distance between your vehicle and the vehicle ahead. This feature can be thought of as an enhancement to the cruise control feature, which is offered to enhance driver's comfort in many current vehicles.

As a test participant, you will drive a real car at speeds ranging from 30-60 mph. As a safety precaution, the object you will be driving behind is an "artificial" rear-end of a vehicle. This "artificial car" will be towed about 40 feet (or one and one half car lengths) behind a real car. You will be asked to simply follow this artificial car at your normal following distance under a variety of conditions. The passenger in the car you will be driving will be a trained General Motors Milford Proving Ground test driver. The test driver will have access to passenger-side brakes and will override your braking in the event it becomes necessary. If you do collide with the lead vehicle, you should know that the artificial car is constructed of a material such that, if struck, it is designed not to cause injury to either the test participant or researchers. During the testing you will be asked to complete a questionnaire about your experience. At no time will you be asked to perform any unsafe driving actions.

You must have a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of 2 years driving experience, be 20 years of age or older, have normal hearing and vision (with correction allowed), be able to drive an automatic transmission vehicle without assistive devices or special equipment, be able to give informed consent, and not be under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair your ability to drive.

In addition you must not have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or be pregnant. You must not have used alcohol, drugs, or any other substances (e.g., antihistamines) which will impair your ability to drive for a period of no less than 24 hours prior to participation.

Risks: There are some risks and discomforts to which you expose yourself in volunteering for this research. This includes the risk of an accident normally associated with driving and braking a vehicle in response to a stopped or slowing lead vehicle. Unlike in normal driving, this stopped or slowing lead vehicle will be an artificial vehicle attached to a collapsible beam, and your passenger will be a trained General Motors Milford Proving Ground test driver. This test driver will have access to passenger-side brakes and will override your braking in order to avoid collisions with the artificial car. If an accident does occur, the experimenters will arrange medical transportation to the Milford Proving Ground Medical facility. You will be required to undergo examination by medical personnel there. You will be responsible for making arrangements for payment of subsequent treatment.

Benefits: There are no direct benefits to you from this research other than compensation for your time and effort. However, by participating in this study, you are lending your experience as a driver to research aimed at understanding how to properly design a feature for cars which would automatically adjust the distance between a driver's vehicle and the vehicle ahead. You will not be informed as to the results of this study.

Payment: You will be paid $150 for participation in this study. The study will take about 2-2 ½ hours. Payment will be made by check at the time of participation.

Withdrawal: Participation in this study is voluntary. You may withdraw at anytime, for any reason, without penalty. Should you withdraw, you will still be paid in full.

Confidentiality: The data gathered in this study will be treated with anonymity. Shortly after you have participated, your name will be separated from your data and it will be given a number. Only the Principle Investigator will have access to this coding information. Your name will not appear in any reports or papers written about the project. Any videotapes of the data, which will include video of the your head and face, will be kept until they are no longer needed. Confidentiality of this video information will be protected.

The researchers hope that you will agree to participate in this study. If you have any questions, please feel free at any time to ask the experimenter.

Once you have had your questions answered, please let the experimenter know whether you are interested in participating in this study. If you are willing to participate, the experimenter will ask you some questions to ensure that your background and experience match our research needs. If it is determined that you qualify to participate, you will be asked to read and sign an Informed Consent Form before you can actually participate in the study.

A9 / STUDY 3 - INFORMED CONSENT

I, ______________________________, agree to participate in research aimed at understanding how to properly design a feature for cars which would automatically adjust the distance between a driver's vehicle and the vehicle ahead.

1. You are being asked to volunteer to be a subject in a research project whose purpose and description are contained in the Information Letter. The purpose of this research program is to understand how to properly design a feature for cars that would automatically adjust the distance between a driver's vehicle and the vehicle ahead. As a test participant, you will drive a real car at speeds ranging from 30-60 mph. As a safety precaution, the object you will be driving behind is an "artificial" rear-end of a vehicle. This "artificial car" will be towed about 40 feet (or one and one half car lengths) behind a real car. You will be asked to simply follow this artificial car at your normal following distance under a variety of conditions. The passenger in the car you will be driving will be a trained General Motors Milford Proving Ground test driver. The test driver will have access to passenger-side brakes and will override your braking in the event it becomes necessary. If you do collide with the lead vehicle, you should know that the artificial car is constructed of a material such that, if struck, it is designed not to cause injury to either the test participant or researchers. During this testing, you will be asked to complete a questionnaire about your experience. At no time will you be asked to perform any unsafe driving actions.

There are some risks and discomforts to which you expose yourself in volunteering for this research. These include the risk of an accident normally associated with driving and braking a vehicle in response to a stopped or slowing lead vehicle. Unlike in normal driving, this stopped or slowing lead vehicle will be an artificial vehicle attached to a collapsible beam, and your passenger will be a trained General Motors Milford Proving Ground test driver. This test driver will have access to passenger-side brakes and will override your braking in order to avoid collisions with the artificial car.

3. The following precautions will be taken during your drive:

The experimenter will always be present in the test vehicle and will monitor your driving. They will ask you to discontinue participation if they feel the risks are too great to continue. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe, legal manner.

The front seat experimenter will have an override brake pedal.

The vehicle is equipped with a driver-side airbag and anti-lock brakes. Air bags inflate with great force, faster than the blink of an eye. If you're too close to an inflating air bag, it could seriously injure you. Safety belts help you keep in position before and during a crash. You should always wear your safety belt, even with air bags. You will be required to wear your lap and shoulder belt system during this test anytime the car is moving. You should sit as far back as possible while still maintaining control of the vehicle.

The vehicle is equipped with a fire extinguisher and first aid kit. The lead vehicle has a cellular phone.

If an accident does occur, the experimenters will arrange medical transportation to the Milford Proving Ground Medical facility. You will be required to undergo examination by medical personnel in the emergency room. You will be responsible for making arrangements for payment of the expenses of such treatment.

Trained medical personnel will be immediately accessible by phone at all times during testing.

4. The data gathered in this study will be treated with anonymity. Shortly after you have participated, your name will be separated from your data and it will be given a number. Only the Principle Investigator will have access to this coding information. Your name will not appear in any reports or papers written about the project. Any videotapes of the data, which will include video of your head and face, will be kept until they are no longer needed. Confidentiality of this video information will be protected. It is possible that, should you be involved in an accident during testing, that the researchers will have to release your data on your driving in response to a court order.

5. You will be paid $150 for participation in this study. The study will take about 2-2 ½ hours. Payment will be made by check at the time of participation.

6. There are no direct benefits to you from this research other than payment. However, by participating in this study, you are lending your experience as a driver to research aimed at understanding how to properly design a feature for cars which would automatically adjust the distance between a driver's vehicle and the vehicle ahead. You will not be informed as to the results of this study.

7. By agreeing to participate, you certify that you possess a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of 2 years driving experience, be 20 years of age or older, have normal hearing and vision (with correction allowed), are able to drive an automatic transmission vehicle without assistive devices or special equipment, are able to give informed consent and are not under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair your ability to drive. You also certify that you do not have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or are pregnant. Additionally, you have not used alcohol, drugs, or any other substances (e.g., antihistamines) which will impair your ability to drive for a period of no less than 24 hours prior to participation.

8. The experimenters will answer any question that you might have about this project and you should not sign this informed consent form until you are satisfied that you understand all of the previous descriptions and conditions. You may contact the principal investigator at the following address and telephone number:

Raymond J. Kiefer, Ph.D.
CAMP
Discovery Centre
39255 Country Club Drive
Suite B-30
Farmington Hills, MI 48331
(248) 848-9595 ext. 15

9. If information becomes available which might reasonably be expected to affect your willingness to continue participating in this study, this information will be provided to me.

10. Participation in this study is voluntary. You may withdraw from this study at any time, and for any reason, without penalty. Should you withdraw, you will still be paid in full.

11. By signing this form you certify, to the best of your knowledge, you have no physical ailments or conditions which could either be further aggravated or adversely affected by participation in this study.

I have read and understand the scope of this research program and I have no other questions at this time. I understand that I am free to ask questions at any time. I hereby give my consent to participate, but I understand that I may stop at anytime, if I choose to do so.

Participant:

Name:____

Address:____

Telephone:____

Signature:______________________________Date:______________

Researcher:

Signature:______________________________Date:______________

A10 / STUDY 3 - TEST INSTRUCTIONS

Before we begin, I would like you to become familiar with this vehicle. Please adjust your seat, steering wheel, and mirrors so that you are comfortable and prepared to drive. Please make sure that your seat belt is securely fastened

Our session today will be conducted on this test track which is closed to all other traffic during the session. This study is being conducted jointly by General Motors and Ford. That is why we are having you drive a Ford Taurus today. The passengers that will be in the car with you are (Test Driver Name) who is a trained General Motors Proving Ground test driver and myself. And I will be giving you directions as we go through the testing session.

The purpose of this study is to examine the distance a driver normally follows the vehicle ahead under a variety of conditions. The conditions will be at speeds ranging from 30 to 60 mph. This information will be used to understand how to design a feature for cars that would automatically adjust the distance between your vehicle and the vehicle ahead. This feature will be used to enhance the cruise control feature on an automobile.

There will be a total of four segments to your session today. During these segments you will be asked to follow the lead car at your normal following distance. The lead car will be travelling at 30, 40, 50, or 60 mph. At each of these four speeds, you will follow the lead vehicle at your normal following distance for approximately 15 minutes. This driving period will allow the computerized distance control feature to "learn" how you like to drive normally. After this learning period, you will drive with the vehicle's cruise control system and the new distance control feature controlling the vehicles speed and following distance. After experiencing the distance control feature at each speed we will ask you questions regarding your preferences about the system.

At no time during the session are we going to ask you perform any unsafe driving actions. In addition, we would like you to know that there are a number of precautions we have taken to ensure your safety today. Your test-driver passenger (Name), has access to passenger-side brakes in the event of an emergency. Also, the vehicle you are following is constructed of a "soft" material that is designed to not cause injury to other vehicles or their occupants when struck. All of our procedures have been designed with safety as the top priority.

Do you have any questions so far?

A11 / STUDY 3 - NAME THE SYSTEM QUESTIONNAIRE

The purpose of this research is to understand how to properly design a feature that would reduce one common type of accident. This accident type occurs when a driver is following another car on a straight road, and then crashes into the back end of that car.

Now that you have some idea about what such a feature would be like, we would like your opinion about what to name the feature. Listed below are names that have been proposed for the new system. When picking the name, please keep in mind that this feature is <u>not</u> designed to detect pedestrians, and this feature would occasionally alert or warn the driver under conditions that pose no threat to the driver.

Please choose three names that you think would be good choices. Number your choices 1 (best), 2 (second best), and 3 (third best).

______ Forward Collision Warning System

______ Forward Collision Alert System

______ Forward Crash Warning System

______ Forward Crash Alert System

______ Front-end Collision Warning System

______ Front-end Collision Alert System

______ Rear-end Collision Warning System

______ Rear-end Collision Alert System

A12 / STUDY 4-SUBJECT INFORMATION LETTER

Dear Participant,

Last year (between mid-August and mid-October) you participated in a research project that was conducted at the Milford Proving Grounds in Milford, Michigan. That project examined driver's braking maneuvers, and is one of a continuing program of research being conducted by Ford and GM. You are now being asked to participate in research that will examine the distance a driver normally follows the vehicle ahead under a variety of situations. The data from this study will provide us with an essential building block for understanding how to design a feature for cars that would automatically adjust the distance between your vehicle and the vehicle ahead. This feature can be thought of as an enhancement to the cruise control feature, which is offered to enhance driver's comfort in many current vehicles.

As a test participant, you will drive a real car at speeds ranging from 30-60 mph. As a safety precaution, the object you will be driving behind is an "artificial" rear-end of a vehicle. This "artificial car" will be towed about 40 feet (or one and one half car lengths) behind a real car. You will be asked to simply follow this artificial car at your normal following distance under a variety of conditions. The passenger in the car you will be driving will be a trained General Motors Milford Proving Ground test driver. The test driver will have access to passenger-side brakes and will override your braking in the event it becomes necessary. If you do collide with the lead vehicle, you should know that the artificial car is constructed of a material such that, if struck, it is designed not to cause injury to either the test participant or researchers. During the testing you will be asked to complete a questionnaire about your experience. At no time will you be asked to perform any unsafe driving actions.

You must have a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of 2 years driving experience, be 20 years of age or older, have normal hearing and vision (with correction allowed), be able to drive an automatic transmission vehicle without assistive devices or special equipment, be able to give informed consent, and not be under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair your ability to drive.

In addition you must not have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or be pregnant. You must not have used alcohol, drugs, or any other substances (e.g., antihistamines) which will impair your ability to drive for a period of no less than 24 hours prior to participation.

Risks: There are some risks and discomforts to which you expose yourself in volunteering for this research. This includes the risk of an accident normally associated with driving and braking a vehicle in response to a stopped or slowing lead vehicle. Unlike in normal driving, this stopped or slowing lead vehicle will be an artificial vehicle attached to a collapsible beam, and your passenger will be a trained General Motors Milford Proving Ground test driver. This test driver will have access to passenger-side brakes and will override your braking in order to avoid collisions with the artificial car. If an accident does occur, the experimenters will arrange medical transportation to the Milford Proving Ground Medical facility. You will be required to undergo examination by medical personnel there. You will be responsible for making arrangements for payment of subsequent treatment.

Benefits: There are no direct benefits to you from this research other than compensation for your time and effort. However, by participating in this study, you are lending your experience as a driver to research aimed at understanding how to properly design a feature for cars which would automatically adjust the distance between a driver's vehicle and the vehicle ahead. You will not be informed as to the results of this study.

Payment: You will be paid $150 for participation in this study. The study will take about 2-2 ½ hours. Payment will be made by check at the time of participation.

Withdrawal: Participation in this study is voluntary. You may withdraw at anytime, for any reason, without penalty. Should you withdraw, you will still be paid in full.

Confidentiality: The data gathered in this study will be treated with anonymity. Shortly after you have participated, your name will be separated from your data and it will be given a number. Only the Principle Investigator will have access to this coding information. Your name will not appear in any reports or papers written about the project. Any videotapes of the data, which will include video of the your head and face, will be kept until they are no longer needed. Confidentiality of this video information will be protected.

The researchers hope that you will agree to participate in this study. If you have any questions, please feel free at any time to ask the experimenter.

Once you have had your questions answered, please let the experimenter know whether you are interested in participating in this study. If you are willing to participate, the experimenter will ask you some questions to ensure that your background and experience match our research needs. If it is determined that you qualify to participate, you will be asked to read and sign an Informed Consent Form before you can actually participate in the study.

A13 / STUDY 4 - INFORMED CONSENT

I, _____________________________, agree to participate in research aimed at understanding how to properly design a feature for cars which would automatically adjust the distance between a driver's vehicle and the vehicle ahead.

1. You are being asked to volunteer to be a subject in a research project whose purpose and description are contained in the Information Letter. The purpose of this research program is to understand how to properly design a feature for cars that would automatically adjust the distance between a driver's vehicle and the vehicle ahead. As a test participant, you will drive a real car at speeds ranging from 30-60 mph. As a safety precaution, the object you will be driving behind is an "artificial" rear-end of a vehicle. This "artificial car" will be towed about 40 feet (or one and one half car lengths) behind a real car. You will be asked to simply follow this artificial car at your normal following distance under a variety of conditions. The passenger in the car you will be driving will be a trained General Motors Milford Proving Ground test driver. The test driver will have access to passenger-side brakes and will override your braking in the event it becomes necessary. If you do collide with the lead vehicle, you should know that the artificial car is constructed of a material such that, if struck, it is designed not to cause injury to either the test participant or researchers. During this testing, you will be asked to complete a questionnaire about your experience. At no time will you be asked to perform any unsafe driving actions.

There are some risks and discomforts to which you expose yourself in volunteering for this research. These include the risk of an accident normally associated with driving and braking a vehicle in response to a stopped or slowing lead vehicle. Unlike in normal driving, this stopped or slowing lead vehicle will be an artificial vehicle attached to a collapsible beam, and your passenger will be a trained General Motors Milford Proving Ground test driver. This test driver will have access to passenger-side brakes and will override your braking in order to avoid collisions with the artificial car.

3. The following precautions will be taken during your drive:

The experimenter will always be present in the test vehicle and will monitor your driving. They will ask you to discontinue participation if they feel the risks are too great to continue. However, as long as you are driving the research vehicle, it remains your responsibility to drive in a safe, legal manner.

The front seat experimenter will have an override brake pedal.

The vehicle is equipped with a driver-side airbag and anti-lock brakes. Air bags inflate with great force, faster than the blink of an eye. If you're too close to an inflating air bag, it could seriously injure you. Safety belts help you keep in position before and during a crash. You should always wear your safety belt, even with air bags. You will be required to wear your lap and shoulder belt system during this test anytime the car is moving. You should sit as far back as possible while still maintaining control of the vehicle.

The vehicle is equipped with a fire extinguisher and first-aid kit. The lead vehicle has a cellular phone.

If an accident does occur, the experimenters will arrange medical transportation to the Milford Proving Ground Medical facility. You will be required to undergo examination by medical personnel in the emergency room. You will be responsible for making arrangements for payment of the expenses of such treatment.

Trained medical personnel will be immediately accessible by phone at all times during testing.

4. The data gathered in this study will be treated with anonymity. Shortly after you have participated, your name will be separated from your data and it will be given a number. Only the Principle Investigator will have access to this coding information. Your name will not appear in any reports or papers written about the project. Any videotapes of the data, which will include video of your head and face, will be kept until they are no longer needed. Confidentiality of this video information will be protected. It is possible that, should you be involved in an accident during testing that the researchers will have to release your data on your driving in response to a court order.

5. You will be paid $150 for participation in this study. The study will take about 2-2 ½ hours. Payment will be made by check at the time of participation.

There are no direct benefits to you from this research other than payment. However, by participating in this study, you are lending your experience as a driver to research aimed at understanding how to properly design a feature for cars which would automatically adjust the distance between a driver’s vehicle and the vehicle ahead. You will not be informed as to the results of this study.

7. By agreeing to participate, you certify that you possess a valid, unrestricted, U.S. drivers license (except for corrective eye glasses), have a minimum of 2 years driving experience, be 20 years of age or older, have normal hearing and vision (with correction allowed), are able to drive an automatic transmission vehicle without assistive devices or special equipment, are able to give informed consent and are not under the influence of alcohol, drugs, or any other substances (e.g., antihistamines) which may impair your ability to drive. You also certify that you do not have a history of heart condition or prior heart attack, lingering effects of brain damage from stroke, tumor, head injury, or infection, epileptic seizures in the past 12 months, shortness of breath or chronic medical therapy for respiratory disorders, a history of motion sickness, a history of inner ear problems, dizziness, vertigo, or balance problems, diabetes for which insulin is required, chronic migraine or tension headaches, or are pregnant. Additionally, you have not used alcohol, drugs, or any other substances (e.g., antihistamines) which will impair your ability to drive for a period of no less than 24 hours prior to participation.

8. The experimenters will answer any question that you might have about this project and you should not sign this informed consent form until you are satisfied that you understand all of the previous descriptions and conditions. You may contact the principal investigator at the following address and telephone number:

Raymond J. Kiefer, Ph.D.
CAMP
Discovery Centre
39255 Country Club Drive
Suite B-30
Farmington Hills, MI 48331
(248) 848-9595 ext. 15

9. If information becomes available which might reasonably be expected to affect your willingness to continue participating in this study, this information will be provided to me.

10. Participation in this study is voluntary. You may withdraw from this study at any time, and for any reason, without penalty. Should you withdraw, you will still be paid in full.

11. By signing this form you certify, to the best of your knowledge, you have no physical ailments or conditions which could either be further aggravated or adversely affected by participation in this study.

I have read and understand the scope of this research program and I have no other questions at this time. I understand that I am free to ask questions at any time. I hereby give my consent to participate, but I understand that I may stop at anytime, if I choose to do so.

Participant:

Name:____

Address:____

Telephone:____

Signature:________________________________Date:________________

Researcher:

Signature:________________________________Date:________________

A14 / STUDY 4 - PART 1 TEST INSTRUCTIONS

Before we begin, I would like you to become familiar with this vehicle. Please adjust your seat, steering wheel, and mirrors so that you are comfortable and prepared to drive. Please make sure that your seat belt is securely fastened.

Our session today will be conducted on this test track which is closed to all other traffic during the session. This study is being conducted jointly by General Motors and Ford. That is why we are having you drive a Ford Taurus today. The passengers that will be in the car with you are (Test Driver Name) who is a trained General Motors Proving Ground test driver and myself. And I will be giving you directions as we go through the testing session.

The purpose of this study is to examine the distance a driver normally follows the vehicle ahead under a variety of conditions. The conditions will be at speeds ranging from 30 to 60 mph. This information will be used to understand how to design a feature for cars that would automatically adjust the distance between your vehicle and the vehicle ahead. This feature will be used to enhance the cruise control feature on an automobile.

There will be a total of four segments to your session today. During these segments you will be asked to follow the lead car at your normal following distance. The lead car will be traveling at either 30, 40, 50, or 60 mph. At each of these four speeds, you will follow the lead vehicle at your normal following distance for approximately 15 minutes. This driving period will allow the computerized distance control feature to “learn” how you like to drive normally. After this learning period, you will drive with the vehicle’s cruise control system and the new distance control feature controlling the vehicle speed and following distance. After experiencing the distance control feature at each speed we will ask you questions regarding your preferences about the system.

At no time during the session are we going to ask you perform any unsafe driving actions. In addition, we would like you to know that there are a number of precautions we have taken to ensure your safety today. Your test-driver passenger (Name), has access to passenger-side brakes in the event of an emergency. Also, the vehicle you are following is constructed of a “soft” material that is designed to not cause injury to other vehicles or their occupants when struck. All of our procedures have been designed with safety as the top priority.

Do you have any questions so far?

A15 / STUDY 4 - PART 2 TEST INSTRUCTIONS

We would like now to go over the instructions for the rest of the study. The real purpose of this study is to understand both when and how to present crash warning information to drivers. Throughout the test, you will be asked to brake in response to crash alerts while approaching the lead “artificial” car. This lead car will be moving. The lead car will be traveling either at 30, 45, or 60 mph. You should follow the lead vehicle, maintaining your normal following distance just as you did before. Please accelerate in a comfortable, quick manner to reach your normal following distance. The lead car driver will brake with various braking intensities throughout the test, ranging from normal braking to relatively hard braking.

It is extremely important that you keep your foot on the accelerator and maintain a steady speed until the crash alert is presented. Once the crash alert is presented, please quickly move your foot from the accelerator to the brake, and brake the car to a complete stop such that you do not collide with the lead “artificial car”. Please brake the car in any way you are comfortable and that you feel is appropriate to avoid colliding with the artificial car. Once again, it is extremely important that you keep your foot on the accelerator and maintain a steady speed until the crash alert occurs.

The test driver will have access to passenger-side brakes. When necessary, the test driver will override your braking to avoid collisions with the lead car. Should this occur, please do not be concerned of frustrated, just do the best you can.

If you now have any questions about the test, please do not hesitate to ask.

A16 / THE TIME-COURSE OF THE BRAKE PULSE ALERT

Table 1 The Time-Course of the Brake Pulse Alert Using 7 Samples at Each Speed With the Highest and Low Values Removed at Each Speed to Reduce Effect of Extreme Values

Brake Pulse Measure	Speed						Overall	
	30 mph		45 mph		60 mph			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Time between alert criterion violation and start of pulse (sec)	0.34	0.07	0.26	0.03	0.31	0.12	0.30	0.08
Time between alert criterion violation and attaining -0.10 g's due to pulse (sec)	0.42	0.07	0.37	0.02	0.43	0.09	0.41	0.07
Time between alert criterion violation and attaining -0.20 g's due to pulse (sec)	0.49	0.07	0.47	0.06	0.54	0.07	0.50	0.07
Time between alert criterion violation and attaining peak deceleration level due to pulse (sec)	0.60	0.08	0.53	0.00	0.60	0.07	0.58	0.06
Time between alert criterion violation and end of pulse (sec)	0.91	0.08	0.87	0.02	0.93	0.12	0.90	0.08
Peak deceleration value attained due to brake pulse (g)	0.26	0.01	0.23	0.01	0.23	0.02	0.24	0.02

Table 2 Time-Course of the Brake Pulse Alert Using All 7 Samples at Each Speed

Brake Pulse Measure	Speed						Overall	
	30 mph		45 mph		60 mph			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Time between alert criterion violation and start of pulse (sec)	0.38	0.16	0.27	0.05	0.31	0.13	0.32	0.12
Time between alert criterion violation and attaining -0.10 g's due to pulse (sec)	0.46	0.17	0.37	0.03	0.43	0.12	0.42	0.12
Time between alert criterion violation and attaining -0.20 g's due to pulse (sec)	0.53	0.16	0.47	0.06	0.53	0.11	0.51	0.12
Time between alert criterion violation and attaining peak deceleration level due to pulse (sec)	0.64	0.16	0.53	0.02	0.60	0.09	0.59	0.11
Time between alert criterion violation and end of pulse (sec)	0.95	0.17	0.88	0.06	0.92	0.14	0.92	0.13
Peak deceleration value attained due to brake pulse (g)	0.26	0.02	0.23	0.02	0.24	0.02	0.24	0.02

A17 / DETAILED BREAKDOWN OF DRIVERS' RESPONSES

Table 3 Detailed Breakdown of Drivers' Responses to the Alert Noticeability Questionnaire for Study 3 and Study 4 (Study 4 shown in parentheses)

Post-Surprise Trial Question and Driver's Response	Crash Alert Type				
	HHDD + Non-Speech	HHDD Flashing + Non-Speech	HHDD + Speech	HUD + Non-Speech	HHDD + Non-Speech + Br. Pulse
If the driver noticed visual alert? Yes	5/12 (3/12)	8/12 (10/12)	3/12	10/12	4/12
What color was the indicator?					
Red, Orange, or Amber for HHDD	4/12 (3/12)	5/12 (7/12)	2/12		4/12
Blue or Green for HUD				9/12	
Where was indicator located? (Correct)	3/12 (2/12)	5/12 (7/12)	1/12	9/12	1/12
Were there letters or a picture, or letter and picture on the indicator?					
Letters Only	1/12 (0/12)	1/12 (1/12)	0/12	3/12	2/12
Picture Only	0/12 (1/12)	0/12 (2/12)	0/12	1/12	0/12
Letter + Picture	0/12 (2/12)	2/12 (1/12)	0/12	4/12	0/12
If you saw letters, what word or words did they spell? "Warning"	1/12 (2/12)	2/12 (1/12)	0/12	5/12	1/12
If you saw a picture, please draw or describe the picture?					
Star (part correct)	0/12	0/12	0/12	1/12	0/12
Arrows + Star	0/12	0/12	0/12	1/12	0/12
Other	0/12 (3/12)	2/12 (3/12)	0/12	3/12	0/12
If the driver noticed the auditory alert? Yes	12/12 (12/12)	12/12 (12/12)	11/12	12/12	11/12
What was the type of sound you noticed? (Correct)	12/12 (12/12)	12/12 (12/12)	11/12	12/12	11/12
Please describe the sound. Tone	12/12 (12/12)	12/12 (12/12)	N/A.	12/12	11/12
Please say the word. "Warning"	N/A.	N/A.	10/12	N/A.	N/A.
If driver noticed the brake pulse alert? Yes	N/A.	N/A.	N/A.	N/A.	12/12
Please describe sensation.	N/A.	N/A.	N/A.	N/A.	
Braking					1/12
Jerk					1/12
Vehicle Hesitation					4/12
Like ABS					1/12
Bump					2/12
Pulse-like sensation-related description provided, however, unlike the descriptions provided above, drivers were unsure of source of sensation					3/12

A18 / PROCESS FOR SELECTING THE VISUAL DISPLAY FORMAT USED FOR CRASH ALERTS IN THE THREE DRIVER INTERFACE STUDIES

Symbol Design

The design of the candidate visual crash alerts initiated with a review of the visual crash alerts tested in a previous study (Jovanis, Campbell, Klaver, & Chen, 1997), production symbols contained in the ISO 2575/1 (1996), and symbols proposed for adaptive and conventional cruise control systems. "Crude" candidate icon drawings were 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. This brainstorming process resulted in the 10 refined candidate visual crash alerts shown and numbered in Figure 1. Symbols 1, 2, 4, 5, 8, and 9 were created by altering current or proposed symbols.

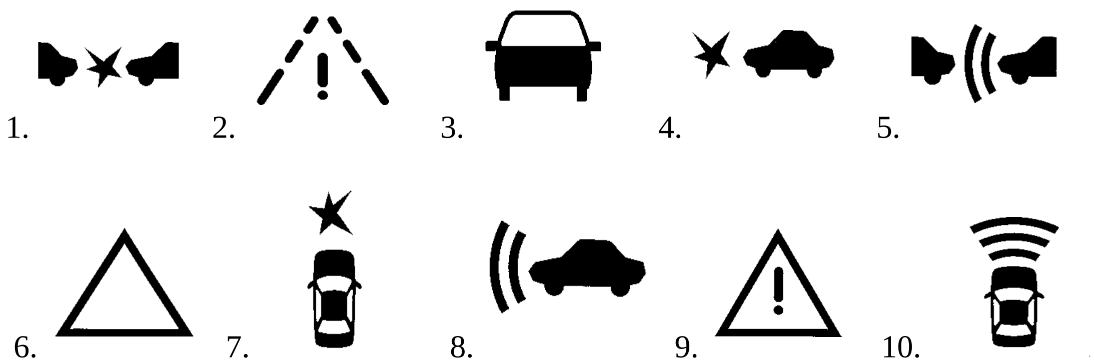


Figure 1 Visual Crash Alert Candidates

In general, the symbols conformed to the ISO 3461 (1976) guidelines for graphical symbols. With the exception of the tapered lines on the star-like crash symbol (symbols 1, 4, and 7), the symbols were designed using lines at least 2 mm in thickness. The symbols were then reduced to fit a 10-mm by 10 mm square, which was the size of the symbols used throughout the study.

Symbol Screening Process

The symbol screening process employed the ANSI Z535.3 (1997) procedures 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.

Comprehension Estimation Testing

To conduct the comprehension estimation procedure, the 10 symbols shown in Figure 1 were printed on one sheet of paper with the intended message stated as follows. "You may be in danger of hitting the vehicle ahead unless you react immediately." The instructions explained that a symbol intended to convey the collision alert message would be shown as a display in a vehicle. Participants were asked to estimate the percentage of drivers they believed would quickly and accurately understand the intended message for each of the 10 symbols. The instructions stated that any number between 0 and 100 could be used for the estimation and that a number could be used as often as desired.

Two groups of participants completed the comprehension estimation procedure. The first group consisted of 12 males and 20 females working outside of the automobile industry. These individuals were operators at a hospital telephone center and students in an introductory engineering class at Wayne State University. These test participants ranged from 20 to 74 years old, with a mean age of 37.4 years (standard deviation=11 years). The second group of participants consisted of 42 male and 11 female industry experts working at General Motors Corporation and Ford Motor Company (The gender of 4 participants included in this analysis were not reported.). These experts had backgrounds in human factors, safety, adaptive cruise control systems, and/or forward collision warning systems. These test participants ranged from 24 to 63 years old, with a mean age of 41.9 years (standard deviation=11 years). These two participant groups provided an opportunity to view the representation of judgments made by industry insiders to that of naive individuals.

The mean comprehension estimates for each symbol are shown in Figure 2. The mean comprehension estimates for the two participant groups, non-automotive and industry experts, are shown separately. The pattern of comprehension estimates for the 10 symbols were similar for both groups. However, overall, the industry experts were more conservative than the non-automotive participants in their estimates. The two symbols with the highest mean comprehension estimates in both groups were symbols 1 and 5. For symbol 1, the two partial vehicles separated by a crash symbol, the non-automotive and industry groups provided mean comprehension estimates of 78.6% and 59.9%, respectively. For symbol 5, the two partial vehicles separated by curved lines resembling radar waves, the non-automotive and industry groups provided mean comprehension estimates of 62.3% and 46.9%, respectively. None of the other eight candidate symbols had mean comprehension estimates over 50%.

Open-Ended Comprehension Testing

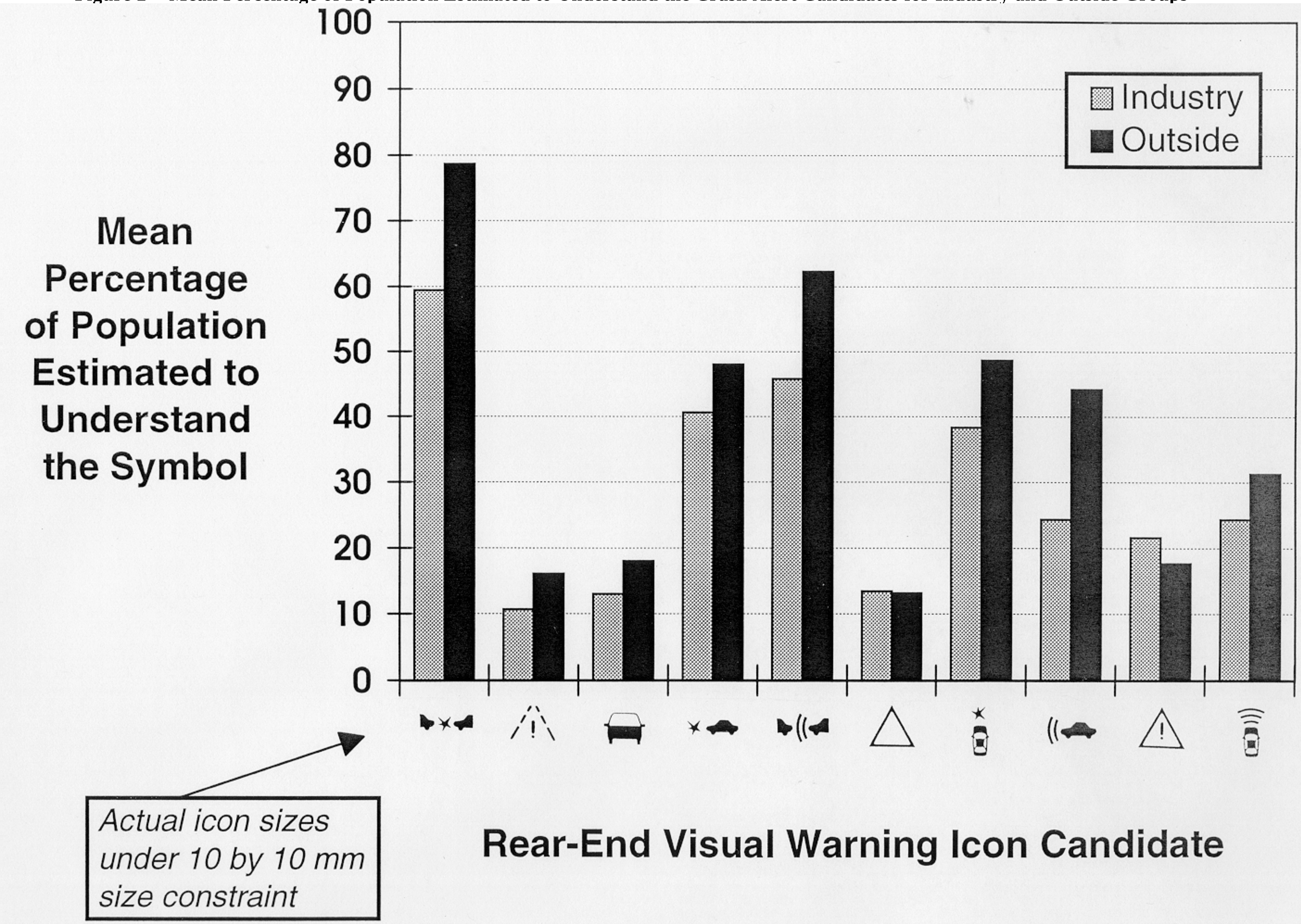
Symbols 1 and 5 were carried over from the comprehension estimation procedure as the candidate symbols for the second stage of testing required by ANSI Z535.3, an open-ended comprehension procedure. Symbol 1 clearly exceeded the 65% comprehension estimation criterion, whereas symbol 5 fell just below this criterion for the relevant, “non-expert” non-automotive group.

Two versions of a paper and pencil survey, one for each symbol, were constructed for the open-ended comprehension testing. The two versions of the survey were identical except for the symbol presented in this test. The survey contained two sections. The first section was an open-ended comprehension test requiring participants to provide written interpretations of the symbol, in accordance with the ANSI Z535.3 procedure. The second section of the survey employed the comprehension estimation procedure employed above to explore the effects of adding the capitalized word “WARNING” to the symbols.

In the instructions at the beginning of the survey, the importance of completing the survey in sequence was stressed. Participants were explicitly instructed to complete each page of the survey before turning to the next page. The instructions also included a discussion about how symbols are used to communicate messages without using words as recommended by the ANSI Z535.3 procedure. Examples of an incomplete and a complete message for a common symbol (i.e., fingers caught between gears) were given to introduce participants to the open-ended message writing task.

For the open-ended comprehension test, the symbol was presented along with a description of the context in which the symbol would appear. A given subject experienced the same symbol in three different contexts. Each successive description provided more contextual information.

Figure 2 Mean Percentage of Population Estimated to Understand the Crash Alert Candidates for Industry and Outside Groups



> *Context 1*: "You are driving your car. You suddenly notice the following yellow/amber indicator on your dashboard light up."
>
> *Context 2*: "You are driving your car. But you are distracted from the driving task. You are not concentrating on driving. You suddenly notice the following yellow/amber indicator on your dashboard light up."
>
> *Context 3*: "You are driving your car. But you are distracted and you are not concentrating on driving. Your car is approaching another car. You suddenly notice the following yellow/amber indicator on your dashboard light up."

Each context, along with the symbol, was on a separate page. Context 1 was presented first followed by context 2 and then context 3. Participants were asked two questions for each context, which are shown below:

1. What would this dashboard indicator mean to you?

2. If you saw this indicator light on your dashboard would you take any action?

   If so, how soon would you take the action described?

   Nine response choices were given for this forced-choice question, shown below. (Participants were instructed to select one response.)

   - Immediately
   - Sometime before ending my drive
   - Immediately after ending my drive
   - Later that same day
   - The next day
   - Within 2-3 days
   - Within one week
   - Sometime after one week
   - Whenever it was convenient

The first question was an open-ended question that required participants to write out their interpretation of the symbol's message. Participants were instructed to provide as much detail as possible in their written responses.

In the second section of the survey, participants were shown four symbols; symbols 1 and 5 with and without the capitalized word "WARNING" printed below the symbol. The letters of this word were 3.2 mm in height, and the entire word extended approximately 3.5 mm beyond the left and right boundaries of the 10-mm by 10 mm square. The instructions informed participants that a symbol may be displayed in a vehicle as part of a collision alert system intended to reduce the number and severity of rear-end crashes. Participants were instructed that the symbol would be used to tell the driver the following message, "you may be in danger of hitting the vehicle ahead unless you react immediately." Participants were then asked to estimate the percentage of drivers they believed would quickly and accurately understand this message for each of the four symbols. This page in the survey was covered by an extra sheet of paper to prevent participants from accidentally viewing the four symbols in this section before they completed the first open-ended section of the survey.

To recruit participants, members of CAMP recruited their families and acquaintances as contacts to then solicit naive participants for the survey. The contacts hand-delivered the surveys to participants, who mailed the completed surveys back to the experimenters in self-addressed stamped envelopes. Participants completed the surveys on a volunteer basis.

Thirty-four participants completed the version of the survey testing symbol 1, the crash symbol, and 30 completed the version testing symbol 5, the radar wave symbol. The crash symbol group of participants consisted of 14 males and 20 females, ranging from 18 to 73 years old, with a mean age of 44.7 years. The radar wave symbol group of participants consisted of 13 males and 17 females, ranging from 23 to 73 years old, with a mean age of 51.7 years.

For each of the three contexts, the responses to question (1) above were categorized into one of six general categories. The six categories were; responses mentioning a collision, responses mentioning proximity, responses mentioning warning, responses stating only an action, responses mentioning a possible error response, and other types of responses. Subcategories within each category are also reported here to provide more detail about the nature of the responses. Responses that included messages from more than one category were categorized into the category closest to the intended meaning of the symbol. For example, consider the following response given for symbol 5; "that at the speed you are going and the distance between cars it will be difficult to slow down in time without hitting the car in front of you." This response was categorized as "mentioning a collision" even though both proximity and the possibility of a collision were stated. Table 4 provides a sampling of the responses in each category.

The majority of open-ended responses for question (1) above were interpretations of the meaning of the symbol, and not simply statements about a driver's reaction to the symbol. Thus, few responses were classified in the action category. Further, participants were very descriptive in their interpretations of the symbols. Very few responses stated that the symbol was a warning without going into more detail about the nature of the warning (i.e., a warning about distance or a collision).

The percentage of responses classified into each response category for both symbols are shown in Table 5. For the crash symbol (symbol 1), the possibility of a collision was the most frequent response in each context. For the radar wave symbol (symbol 5), proximity to another vehicle or an object was the most frequent response. The crash symbol met the ANSI Z535.3 criteria of 85% correct responses in Context 1, Context 2, and Context 3, assuming collision, proximity, and action (brake the car) responses are correct. The crash symbol also generally met the ANSI Z535.3 criteria of no more than 5% errors, which are considered critical confusions for the symbol for both Context 1 and Context 3. For Context 2, two responses (5.9% of the total)

Table 4 Examples of Responses for the Six Response Categories Used in the Open-Ended Comprehension Test

Category	Example of response
Collision	
a) Not specific	"I'm going to hit another car."
b) Rear-end vehicle ahead	"Caution, you are about to hit a vehicle in front of you."
c) Head on	"Oncoming car is going to head on crash with me."
Proximity	
a) To car ahead	"You are following the car in front of you too closely."
b) Not specific	"Vehicle is in close proximity to another."
Warning	
a) Slow/stopped ahead	"The car ahead is slowing down..."
b) Object ahead	"I think it means that there is an object directly in front of you probably less than 5 feet."
Action	"Head up immediately and prepare to swerve or brake."
Error	
a) Rear-end from behind	"Proceed with caution, you are getting very close to the vehicle behind you."
b) Vehicle behind too close	"A vehicle is tail gating too closely."
Other	"Low fluids."

Table 5 Percentage of Responses in Each Category for Symbol 1 (Crash Symbol) and Symbol 5 (Radar Waves)

	Crash Symbol			Radar Waves		
Response Category	Context 1	Context 2	Context 3	Context 1	Context 2	Context 3
Collision						
Not specific	23.5%	41.2%	32.3%	10.0%	13.3%	20.0%
Rear-end vehicle ahead	17.7%	17.6%	17.7%	0.0%	3.3%	3.3%
Head-on	8.8%	5.9%	5.9%	3.3%	3.3%	3.3%
Total collision responses	50.0%	64.7%	55.9%	13.3%	20.0%	26.6%
Proximity						
To car ahead	32.3%	26.5%	32.3%	70.0%	40.0%	53.3%
Not specific	0.0%	0.0%	0.0%	6.7%	13.3%	3.3%
Total proximity responses	32.3%	26.5%	32.3%	76.7%	53.3%	56.6%
Warning						
Slow / stopped ahead	0.0%	0.0%	5.9%	0.0%	3.3%	0.0%
Object ahead	0.0%	0.0%	0.0%	3.3%	0.0%	0.0%
Total warning responses	0.0%	0.0%	5.9%	3.3%	3.3%	0.0%
Action	2.9%	0.0%	2.9%	0.0%	6.7%	13.3%
Error						
Rear-end from behind	0.0%	5.9%	0.0%	3.3%	0.0%	0.0%
Vehicle behind too close	2.9%	0.0%	0.0%	0.0%	0.0%	0.0%
Total error responses	2.9%	5.9%	0.0%	3.3%	0.0%	0.0%
Other	11.8%	2.9%	2.9%	3.3%	16.7%	3.3%

Table 6 Summary of Actions Stated for Each Context

	Crash Symbol		
Action	Context 1	Context 2	Context 3
Slow down/increase distance	41.2%	26.5%	35.3%
Brake only	20.6%	29.4%	29.4%
Brake, steer, chg. lanes	8.8%	5.9%	8.8%
Pay attn., use caution	2.9%	11.8%	0.0%
Stop	2.9%	0.0%	5.9%
Not specific	8.8%	14.7%	17.6%
Pull off road	0.0%	2.9%	0.0%
Other (e.g., check lights, manual, etc.)	14.7%	5.9%	0.0%
None given	0.0%	0.0%	2.9%
Speed up	0.0%	2.9%	0.0%

	Radar Waves		
Action	Context 1	Context 2	Context 3
Slow down/increase distance	56.7%	30.0%	46.7%
Brake only	20.0%	36.7%	26.7%
Brake, steer, chg. lanes	3.3%	0.0%	3.3%
Pay attention, use caution	0.0%	6.7%	3.3%
Stop	6.7%	3.3%	6.7%
Not specific	3.3%	3.3%	0.0%
Pull off road	3.3%	3.3%	3.3%
Other (e.g., check lights, manual, etc.)	3.3%	13.3%	3.3%
None given	0.0%	3.3%	6.7%
Speed up	3.3%	0.0%	0.0%

stated that the driver's vehicle may be rear-ended (One similar response occurred in Context 1.) The responses classified into the other category mentioned the airbag, low fluids, headlights, or the seat belts.

For question (2) above, across the three contexts, an action was indicated in 99.0% and 96.6% of the responses to the crash symbol and radar wave symbol, respectively. Table 6 is a summary of the responses given for the action question. In each context for both symbols, the most common responses were that the driver would either slow down to increase the distance between vehicles or apply the brakes. Some participants stated that they would either brake, steer, or change lanes depending on the situation. The higher rate of "not specific" responses for the crash symbol compared to the radar wave symbol was a result of more responses such as, "yes, as soon as possible," being given for the crash symbol. When specifying how soon they would take the stated action in response to the crash symbol, for Context 1, Context 2, and Context 3, 91%, 94%, and 97% of participants responded they would take action immediately. The corresponding percentages in response to the radar wave symbol were 93%, 83%, and 90%, respectively.

In the second section of the survey, participants were asked to estimate the percentage of drivers in the population that they believed would quickly and accurately comprehend the intended meaning of the symbols. Participants provided estimates for both the crash symbol and the radar wave symbol, with and without the capitalized word "WARNING" printed below it. Table 7 shows the mean estimates for each group of survey participants. Both groups estimated the crash symbol with the word WARNING would be understood by the largest percentage of drivers, with estimates across the two groups within 2% of each other. In contrast, the estimates for the radar wave symbol appear to be strongly influenced by whether participants saw the symbol in the open-ended response portion of the survey. In all cases, adding the word WARNING to the symbol increased comprehension estimates by about 20%.

Table 7 Mean Percentage of Driving Population Estimated to Comprehend Symbols by Open-Ended Comprehension Survey Participants

	Symbol only		Symbol with word WARNING	
Symbol in survey	Crash Symbol	Radar Waves	Crash Symbol	Radar Waves
Crash Symbol	60.0%	31.2%	81.4%	58.1%
Radar Waves	58.0%	52.0%	79.2%	73.8%

Summary of Results from the Visual Display Format Selection Process

As a result of both the comprehension estimation and open-ended comprehension test procedures administered in accordance with ANSI Z535.3 process Symbol 1 (the two partial vehicles separated by a crash symbol with the capitalized word “WARNING”) was used for all three driver interfaces studies (i.e., Study 2, Study 3, and Study 4) as the visual crash alert display format. In conclusion, these results provided a sound empirical justification for the selection of visual display format used in the follow-up, closed-course driver-interface studies.

A19 / PROCESS FOR SELECTING THE SOUNDS USED FOR CRASH ALERTS IN THE THREE DRIVER INTERFACE STUDIES

Auditory Alert Development

A total of 18 sounds were tested as candidates for an auditory crash alert, which are listed and briefly described in Table 8. The 18 sounds were from five categories:

(1) Standard production vehicle chime

(2) The five top-rated sounds (all Non-Speech) evaluated by Tan and Lerner (1995)

(3) Production-oriented non-speech sounds

(4) Speech message alerts

(5) Non-speech sounds developed by the General Motors Noise and Vibration laboratory

The various sounds within each of these last 4 categories will now be discussed in turn. The five Category (2) sounds evaluated were composed of the top 5 (of the 26) rated sounds evaluated in the Tan and Lerner (1995) laboratory study. In this previous study, participants were asked to rate sounds on various attributes including annoyance, appropriateness, discretion, startle, and urgency. (A modified version of this procedure was employed here.) The mean rating on each attribute was then weighted according to “expert” rankings of the importance of each attribute to an auditory crash alert. The five sounds included in the present study received the five highest total weighted scores. These top sounds were all non-speech sounds, which received higher total weighted ratings than any of the ear con (car horn, tire skid) and speech sounds examined. Unlike the current study, the sounds evaluated in the Tan and Lerner study were examined for their merit as a “master” auditory crash alert, which was intended to precede a subsequent alert indicating direction of threat (e.g., forward).

The seven Category (3) sounds evaluated were modified standard production chimes. These modified chimes had frequencies of 750 Hz, 2000 Hz, or both. In general, the attack/decay characteristics and the cadence of the production chimes were modified to create warning-like sounds (e.g., ambulance, and alarm clock).

The three Category (4) sounds evaluated were the speech alerts “danger”, “warning”, and “look out”. To create these candidates, a male professional broadcaster repeated these warnings three times in sequence. Reverberation was added to the recording of each alert.

The two Category (5) sounds evaluated developed by the General Motors Noise and Vibration laboratory specifically for this test. These sound candidates were created by mixing pulses at frequencies of 2000 Hz and 2500 Hz. The two sounds were identical except that one had a faster cadence.

All 18 sounds were digitized with the assistance of the General Motors Noise and Vibration Center. With the exception of the Category (4) sounds, each of the sounds were 2.10 seconds in length. The category (4) speech alert sounds “danger”, “warning”, and “look out”, were 2.60, 2.49, and 2.42 seconds in length, respectively.

Loudness Adjustment Procedure

A staircase threshold procedure was conducted to attempt to equate the sounds for subjective loudness, so that sounds could be subsequently evaluated for their “pure” crash alert properties independent of subjective loudness. Previous work has indicated that subjective loudness is highly correlated with crash alert properties (e.g., a louder sound is perceived as more urgent) (Tan and Lerner, 1995). The loudness adjustment procedure involved comparing each candidate sound to the standard production chime and judging whether the candidate sound was louder or softer than the standard chime. On each presentation of a sound pair, the loudness of the candidate sound was adjusted one decibel until the rater’s response changed. The initial direction of the decibel change, increasing or decreasing, was randomly varied across the candidate sounds. Once the rater’s response changed, the direction of the loudness adjustment was reversed. This adjustment sequence continued until five response changes occurred. The decibel level of the last four response changes was averaged for each candidate sound. This average represented the decibel level at which the rater judged the loudness of the candidate sound to be equal to that of the standard chime. The loudness adjustment procedure was used with four raters (2 females, average age 30; 2 males, average age 40). The mean of the four raters’ average decibel levels for each sound was then used to compute the decibel adjustment. The decibel adjustments for the candidate sounds were as follows: #4, -6 dBa; #5, -7 dBa; #6, -4 dBa; #7, -6 dBa; #8, -4 dBa; #12, -1 dBa; #19, 0 dBa; #20, -1 dBa; #21, -1 dBa; #22, -4 dBa; #24, -8 dBa; #25, -10 dBa; #26, -10 dBa; #27, -7 dBa; #28, -10 dBa; #29, -2 dBa; and #30,-2 dBa.

Table 8 Brief Description of Collision Alert Sound Candidates

Sound #	Description
	Standard Production Chime
1	2000 Hz production chime, cadence 3.3 per second
	The five top-rated sounds (all Non-Speech) evaluated by Tan and Lerner (1995)
4	Stimuli 1 (low fuel warning)
5	Stimuli 4 (high-pitched, ambulance-like siren)
6	Stimuli 5 (low-pitched, ambulance-like siren)
7	Stimuli 8 (2500 & 7500 Hz 100 ms broad pulse of 110 ms each, repeated at 8 ms intervals, pause of 110 ms)
8	Stimuli 10 (2500 & 2650 Hz peaks, temporally similar to preceding sound)
	Production Oriented Non-Speech Sounds
12	2000 Hz production chime, pulse=7.5 ms attack followed by 142.5 ms decay, cadence 3.3 per second
19	Same as sound 12, using 750 Hz zone
20	Sounds 12 & 19 together (2000 & 750 Hz)
21	Beep 4H33, 2000 Hz, cadence 100 (3.3 sec)
22	2000 Hz production chime, pulse=7.5 ms attack followed by 142.5 ms decay, 4 pulse sequence separated by 110 ms silent pause
27	2000 & 750 Hz production chime overlaid, cadence 3.3 per sec
28	750 & 2000 Hz chimes, alternating (ambulance-like siren)
	Speech Message Alerts
24	“Danger, danger, danger”
25	“Look out, look out, look out”
26	“Warning, warning, warning”
	GM Noise and Vibration Laboratory
29	2000 & 2500 Hz triangular wave tones overlaid
30	Same as sound 29, faster cadence

Sound Evaluation Ratings

Ten DAT recordings of the 18 candidate sounds were created for the sound evaluations. A different random order of the candidate sounds was used for each recording. The interior sound of a 1997 Ford Taurus SHO traveling on dry, smooth pavement at 70 mph was used as background noise for the recordings. The background noise was presented continuously on each recording. The candidate sounds were presented at 12-second intervals “on top of” (or overlaid upon) the background noise.

After listening to verbal instructions (which are described below), participants were asked to rate each sound on the 13 statements shown in Table 9. The order of the statements shown in this table corresponds to the order in which the participants experienced the statements. Participants provided their general opinion of each sound by rating the sounds on the statement, “this sound is a good choice for a collision warning sound.” The participants rated each sound on this general opinion statement twice, initially on the first trial (Statement 1) and then again on the second from last trial (Statement 12). The practice statement, “this sound is very musical”, was used to acquaint participants to the sounds and the sound rating procedure.

Eleven of the 12 remaining statements were related to attributes considered critical for an effective warning sound. These attributes were notability, confusability, attention-getting, startle, interference, annoyance, appropriateness, emergency, and loudness. With the exception of the annoyance and interference attributes, each attribute was addressed by one corresponding statement. For the interference attribute, one statement asked whether the sound would interfere with the driver’s ability to <u>decide</u> on an emergency driving action (Statement 6). Another related statement asked whether the sound would interfere with the driver’s ability to <u>perform</u> an emergency driving action (Statement 7). For the annoyance attribute, one statement asked whether the sound would annoy the driver if the alert came on when no driving action was required <u>once a day</u> (Statement 8). Another related statement asked whether the sound would annoy the driver if the alert came on when no driving action was required <u>once a week</u> (Statement 9). One critical difference between the current study and the Tan and Lerner (1995) study which should be stressed is that drivers in the latter study were told to assume “minimal” false alarms, where minimal was left undefined. It is quite possible that the Tan and Lerner participants idea of “minimal” corresponded to a false alarm (or nuisance alert) frequency of substantially less than once a week.

Table 9 Rating Scale and Statements Used for Sound Ratings

-3	-2	-1	0	1	2	3
Strongly Disagree	Moderately Disagree	Perhaps Disagree	Neutral	Perhaps Agree	Moderately Agree	Strongly Agree

Practice: This sound is very musical.

1. This sound is a good choice for a collision warning sound.
2. This sound would clearly stand out and be noticeable among the other noises inside and outside the vehicle such as engine noise, the fan blowing, talking and music on the radio, horns, and sirens. (Notability)
3. This sound would be confused with other sounds inside and outside the vehicle such as engine noise, talking and music on the radio, horns, sirens, car phones, or other electronic devices. (Confusability)
4. This sound would get my attention immediately. (Attention-getting)
5. This sound would startle me, that is, cause me to blink, jump, or make a rapid reflex-like movement. (Startle)
6. This sound would NOT interfere with my ability to make a quick and accurate decision about the safest driving action to take. (Interference)
7. This sound would NOT interfere with my ability to quickly and accurately perform an emergency driving action. (Interference)
8. This sound would annoy me if it came on once a day in a situation where NO driving action was required. (Annoyance)
9. This sound would annoy me if it came on once a week in a situation where NO driving action was required. (Annoyance)
10. This sound would appear out of place as a warning in a car or truck. (Appropriateness)
11. This sound would clearly tell me that I'm in danger and I need to react immediately. (Emergency)
12. This sound is a good choice for a collision warning sound.
13. This sound seemed louder than the other sounds in the test. (Loudness)

At the start of the session, the experimenter told participants that the evaluation was part of the selection process for a collision warning sound. The text of the verbal instructions are shown on the last page of this Appendix. As a means of explaining the context and requirements of the warning sound, participants were asked to recall their experiences from CAMP Study 1 in which they had to brake hard at the last second possible to avoid colliding with a lead (surrogate) vehicle. They then were told to imagine that they were driving on a real road and to suppose that they were distracted or not paying attention to their driving. Further, when their vehicle rapidly approached a slower or stopped vehicle, the collision warning would sound to alert them to the situation. The instructions stated that once the warning sounded, a driver would have to decide upon the appropriate driving action to take. If braking was appropriate, they were told they would have to use hard braking as in the previous study. Participants were told that this depiction demonstrated that the warning sound must get the driver's attention while allowing the driver to respond appropriately. The possibility of false alarms, or instances when the warning may sound in response to non-threatening events (such as a guardrail on a sharp curve) was then described to explain that the warning sound needed to be attention-getting without being overly annoying.

The participants were then instructed that they would be listening to the candidate warning sounds and rating the extent to which they agreed with various statements made about the sounds. Participants were asked to rate the extent to which they agreed with each statement for each sound using a 7-point scale which ranged from strongly agree (3) to strongly disagree (-3), shown in the top portion of Table 9. The attributes related to each statement (which were not shown to the subjects) are shown in parentheses. The statements are listed in Table 9in the order they were presented during each evaluation session. Participants were instructed to circle a number on the scale to reflect their agreement with the statement for that sound. For example, using the practice statement "this sound is very musical," participants were told that they should circle the response on the scale that reflected the extent to which they agreed that the sound was very musical. After the practice trial, participants were encouraged to ask questions about the procedure and rating scale.

At the beginning of each trial, subjects would hear the experimenter read the statement aloud to the group. The participants then listened to each 18 candidate alert sounds examined (presented in a random order) and rated each sound on the statement. Between each sound presentation, subjects were provided ample time to make sound ratings. All the sounds were rated on a statement before the next statement was introduced. The 13 statements were presented in the order shown in Table 9. Thus, subjects rated each of the 18 sounds 13 times for a total of 234 sound rating trials.

Fifteen females and 20 males participated in the evaluation of the alert sounds. All of these individuals had previously participated in CAMP Study 1, in which they were asked to make last-second hard braking judgements while approaching the slowing or stopped CAMP surrogate (lead vehicle) target. The mean age of the participants was 49 years old (standard deviation=16 years). Participants were either in their 20s, 40s or 60s, which corresponds to the three age groups tested in CAMP Study 1. The 20s group consisted of 8 males and 1 female, the 40s group consisted of 5 males and 6 females, and the 60s group consisted of 7 males and 8 females. Eight individuals from each gender by age category were originally recruited. However, thirteen individuals (including 7 young females) did not appear for testing. All participants reported normal hearing ability. Participants received $35 for completing the 75-minute testing session.

The evaluation sessions were conducted with small groups of one to six participants, depending on participant turnout. Participants were seated in a conference room with their backs to a large table. The seating arrangement prevented participants from viewing each other's facial reactions to the sounds. The sounds were presented using a DAT player, amplifier, and headphones. Participants provided written responses to the statement ratings using clipboards.

The mean agreement rating for each candidate alert sound on each of the 13 statements is shown in Table 10. On Statement 1, which asked participants whether they agreed that a sound was a good choice for a collision alert sound, all of the sounds had a mean rating between +1 and -1. Thus, overall, none of the sounds were strongly favored on the first trial by the participants in general. The sounds which received mean ratings greater than zero, in order of the highest rating, were #7, #30, #26, #6, #8, #29, #24, #4, and #21. These sounds had mean ratings ranging between +0.09 and +0.51. On Statement 12, participants were again asked whether each sound would be a good choice for a collision warning sound. The results for this question differed from those from Statement 1. Three sounds had mean ratings greater than positive one. These sounds were #26, #24, and #25, which correspond to each of the three speech alert sounds examined. Only three other sounds (#8, #30, and #6) had positive mean ratings on this statement. It should be noted that, with respect to interpreting the absolute (as opposed to the relative) ratings provided on the 7-point scale employed, a general preference for speech alerts may have penalized the ratings for all non-speech alerts. That is, if speech alerts had not been included in the set of sounds examined, it seems quite likely that the non-speech sounds would have received higher absolute ratings on the rating scale provided.

Results from Statement 12 are considered the most informative for two primary reasons. First, by the time they completed this statement, participants had been "educated" about the desirable attributes of a collision warning. Second, by this time, participants had heard each sound 12 times, which gave them additional sound experiences to make relative comparisons between alerts, and gave them a chance to determine which alerts still "stuck out" as having alerting qualities during this somewhat lengthy, monotonous rating task. Table 11 lists the sounds in rank order according to the mean ratings on Statement 1 and Statement 12. Three sounds, #26 ("warning", "warning", "warning"), #8 and #30, were in the top five rankings as good choices for a warning at both the beginning and the end of the evaluation.

There are two striking differences between these findings and those reported in Tan and Lerner (1985). First, the top-rated sound from the Tan and Lerner (1995) study, an off-the-shelf low fuel aircraft warning (#4 in this study), fell in the middle of the pack of the sounds rated, and was rated particularly poorly on the annoyance and interference statements. This difference in studies is undoubtedly due to the difference in assumptions provided to raters across studies with respect to nuisance alert frequency. (However, overall, it should be noted that the 5 non-speech sounds carried over from the Tan and Lerner (1985) study performed quite well relative to the 18 sounds examined.) Second, the speech alert sounds in this study were rated substantially higher than the male and female synthesized and digital speech alerts examined in the Tan and Lerner study (none of which were among the top five highest total ratings in this previous study) . This is unlikely due to the relatively minor procedural differences between studies, but instead, in all likelihood is due to differences across studies in the specific nature of the speech stimuli employed.

The last statement asked participants whether a sound seemed louder than the other sounds in the evaluation. The mean ratings for the candidate sounds on the loudness statement ranged from +1.69 to -1.97. Thus, even though the decibel levels of the sounds had been adjusted in an attempt to equate them for subjective loudness prior to the evaluations, participants still reported that some sounds appeared louder or softer than others. A scatter plot, shown in Figure 1, shows the relationship between perceived loudness and participants' final rating of the candidate sounds (Statement 12). The plot incorporates a regression line, which describes the final rating for the candidate sound as a function of the loudness rating. In general, sounds located above the line were rated more highly as a choice for a collision alert than would be expected if the rating was based solely on the perceived loudness of the sound. Conversely, sounds located below the line were rated more poorly as a choice for a collision alert than would be expected if the rating was based solely on the perceived loudness of the sound. The observation that appears most striking in this scatter plot is participants' preference for speech alerts (i.e., #24, #25, and #26).

Table 10 Mean Agreement Rating for Each Candidate Crash Alert Sound Across Each of the Thirteen Sound Rating Statements

	Sound Rating Statement Number												
Sound Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	-0.94	-0.76	1.17	-0.51	-1.53	1.30	0.64	0.75	0.45	0.58	-1.27	-1.74	-0.40
4	0.10	1.74	-0.81	2.40	1.93	-0.97	-0.79	2.51	1.97	0.87	2.03	-0.18	1.69
5	-0.76	0.43	1.10	0.57	-0.65	1.03	0.90	1.06	0.63	0.77	0.27	-1.03	-0.14
6	0.37	1.26	0.26	1.74	1.03	0.17	-0.09	1.71	1.54	0.11	1.37	0.03	1.54
7	0.51	1.43	-0.46	1.43	0.57	0.69	0.63	1.31	1.11	0.00	1.14	-0.09	1.14
8	0.31	1.53	-0.49	1.86	1.20	0.29	0.43	1.54	1.51	-0.74	1.46	0.66	1.51
12	-0.03	-0.49	1.46	-0.06	-1.73	1.48	1.71	-0.20	-0.47	-0.51	-0.44	-0.73	-0.80
19	-0.09	-0.11	0.83	0.29	-1.28	1.34	1.47	-0.20	-0.06	-0.50	-0.30	-0.87	0.17
20	-0.03	0.54	0.43	0.49	-1.09	1.60	1.54	0.03	-0.14	-0.86	0.14	-0.09	0.06
21	0.09	-0.74	1.29	0.43	-1.51	1.49	1.40	0.09	-0.17	-0.80	-0.49	-0.91	-0.54
22	-0.29	-0.74	1.00	-0.26	-1.57	1.63	1.46	-0.11	-0.86	-0.11	-0.77	-0.74	-0.97
24	0.21	1.54	-2.03	2.31	0.69	0.57	1.29	0.66	0.14	-1.49	2.40	1.77	0.91
25	-0.50	1.45	-2.03	2.37	1.13	0.46	0.77	0.97	0.46	-1.23	2.72	1.26	0.91
26	0.40	1.57	-2.03	2.27	0.23	1.06	1.26	0.29	-0.03	-1.44	2.13	1.86	0.26
27	-1.17	-1.83	1.74	-1.29	-2.00	1.49	1.57	-0.20	-0.31	0.66	-1.69	-2.20	-1.94
28	-0.29	-0.65	1.63	-0.33	-1.43	1.54	1.28	-0.07	-0.30	-0.03	-0.46	-1.40	-1.97
29	0.23	0.40	-0.31	1.06	0.10	1.31	1.20	0.40	-0.10	-1.00	0.17	-0.09	1.20
30	0.51	0.86	-0.46	1.34	-0.06	0.83	1.17	0.60	0.03	-1.00	0.69	0.26	0.86

Table 11 Sounds Ranked on Mean Ratings for Statement 1 and Statement 12

Rank	Statement 1	Statement 12
1	30	26
2	7	24
3	26	25
4	6	8
5	8	30
6	29	6
7	24	7
8	4	29
9	21	20
10	12	4
11	20	12
12	19	22
13	22	19
14	28	21
15	25	5
16	5	28
17	1	1
18	27	27

Weighted Sound Ratings

In addition to viewing participant's ratings for the sounds on each statement separately, a total score, or sum of the mean ratings on various attributes, was created for each sound. Each mean rating was weighted according to expert judgments about the importance of the attribute to an auditory alert. The weights used in this study were adapted from the Tan and Lerner (1995) study. To create the attribute weights, Tan and Lerner asked 36 experts in the human factors and safety community to rate the importance of thirteen attributes on a scale of 1 to 10. The mean of the experts' importance ratings for each attribute became the weight for the attribute. Eight attributes from the Tan and Lerner study corresponded closely to eight statements rated in the present study. Table 12 shows the attribute and weighting from the Tan and Lerner study along with the corresponding statement from the present study. A ninth statement, Statement 8, which asked whether a sound would be annoying if it occurred once a day as a nuisance alert, was also included in the set of weighted attribute statements. Because a nuisance alert rate of once a day depicts a situation where annoyance may become a critical negative attribute, this statement was set equal to the highest weight from the group of eight attributes (i.e., 9.43 / Noticeability). In this weighting analysis, the "once a week" nuisance alert assumption was assumed to correspond to the general "minimal" false alarm assumption used by Tan and Lerner (1995).

To create the weighted attribute totals, the ratings were first transformed to a scale of 0, strongly disagree, to 6, strongly agree. This was accomplished by adding 3 to each mean rating. Also, the weights for the attributes discriminability and appropriateness, which were positive weights in the Tan and Lerner (1995) study, were changed to negative weights. This change was made because, as negatively worded statements, higher ratings for Statement 3 and Statement 10 reflected more of a negative attribute for the sound. Finally, each mean rating was multiplied by its attribute weight. Two weighted attribute totals were then summed. A total of the weighted mean ratings excluding the mean rating for the annoyance - once per day statement (i.e., assuming nuisance alerts occur once a week), and a total excluding the mean rating for the annoyance - once per week statement (i.e., assuming nuisance alerts occur once a day).

Table 13 shows the two weighted mean rating totals for each sound in rank order as well as the sounds in rank order according to their mean ratings on Statement 12. The three sounds that ranked highest according to these weighted mean attribute ratings were #26, #24, and #25. These sounds were all speech alerts, corresponding to "warning", "danger", and "look out", respectively. Of the three speech sounds, #26 ("Warning", "Warning", "Warning") slightly outperformed the other speech sounds, as is evident in Table 13. In contrast to these speech alerts, the rank order of the remaining non-speech alerts was somewhat influenced by the annoyance attribute. Based on the drivers' overall ratings provided for the non-speech sounds (Statement 12), sounds #8 and #30 appear most promising, coming in fourth and fifth respectively in the final overall ratings. A closer look at the individual statement ratings (shown in Table 10) suggested that Sound #8 may more appropriate for more of an imminent-type or 1-stage alert crash sound, whereas sound #30 may be more appropriate for more of a cautionary-type crash alert.

Figure 3 Scatter Plot of Final (Statement 12) Ratings by Loudness Ratings for Each of the Candidate Alert Sounds

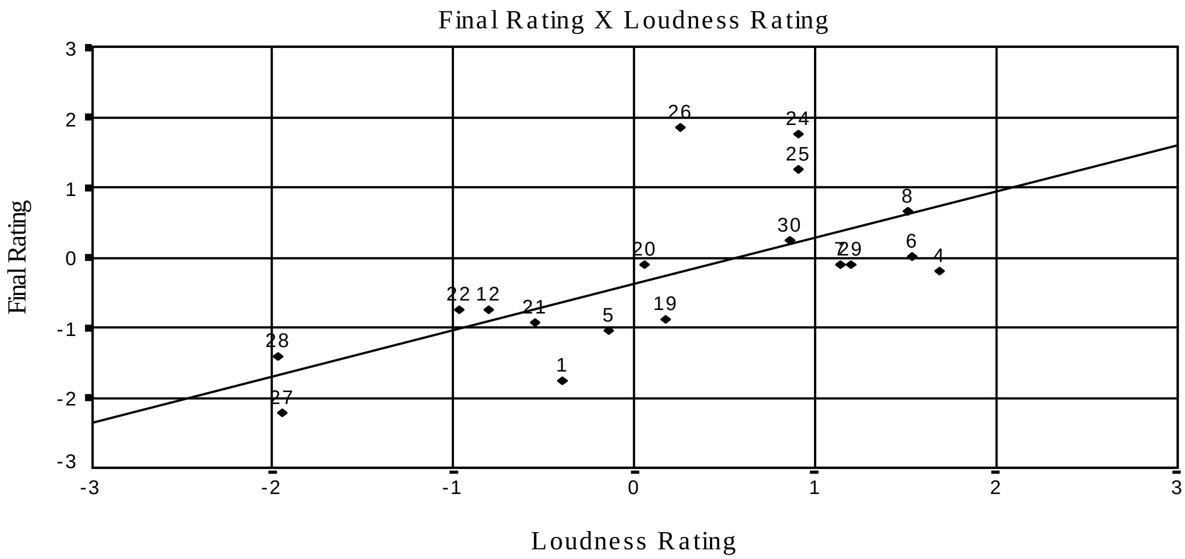


Table 12 Attribute and Weight with the Corresponding Sound Rating Statement

Weight	**Attribute**	**Sound Rating Statement (Sound # in the current study)**
9.43	Noticeability	This sound would clearly stand out and be noticeable among the other noises inside and outside the vehicle such as engine noise, the fan blowing, talking and music on the radio, horns, and sirens (#2)
-9.23	Discriminability	This sound would be confused with other sounds inside and outside the vehicle such as engine noise, talking and music on the radio, horns, sirens, car phones, or other electronic device (#3)
8.80	Urgency	This sound would get my attention immediately (#4)
-7.60	Startle	This sound would startle me, that is, cause me to blink, jump, or make a rapid reflex-like movement (#5)
8.63	Natural Response	This sound would not interfere with my ability to make a quick and accurate decision about the safest driving action take (#6)
-9.43	Annoyance	This sound would annoy me if it came on once a day in a situation where NO driving action was required (#8) (*Note: See text for explanation of this weighting.)*
-4.37	Annoyance	This sound would annoy me if it came on once a week in a situation where NO driving action was required (#9)
-5.66	Appropriateness	This sound would appear out of place as a warning in a car or truck (#10)
7.63	Emergency Relationship	This sound would clearly tell me that I'm in danger and I need to react immediately (#11)

Note: Statement 8 was excluded in this weighting analysis because no attribute referred to a sound's influence on the ability to perform an emergency driving action

Table 13 Sounds Ranked by Weighted Mean Rating Totals for Attribute Statements (Totals weighted mean ratings in parentheses)

	Weighting Analysis Mean Rating Totals		
	Annoyance Assumption (or Assumed Nuisance Alert Frequency)		Overall Rating (Statement 12)
Rank	**Once per week…**	**Once per day…**	
1	26 (108)	26 (90)	26
2	24 (102)	24 (82)	24
3	25 (97)	25 (75)	25
4	30 (65)	30 (45)	8
5	8 (60)	20 (41)	30
6	7 (59)	29 (37)	6
7	20 (57)	8 (37)	7
8	29 (57)	7 (36)	29
9	4 (47)	19 (25)	20
10	6 (44)	6 (20)	4
11	19 (39)	21 (17)	12
12	21 (34)	12 (16)	22
13	12 (32)	4 (16)	19
14	5 (31)	22 (11)	21
15	22 (29)	5 (8)	5
16	28 (21)	28 (5)	28
17	1 (8)	1 (-12)	1
18	27 (-9)	27 (-24)	27

Summary of Results from the Sound Selection Process

This study built upon previous work conducted by Tan and Lerner (1995), which examined 26 sounds, including various non-speech, ear con (car horn, tire skid) and speech sounds. The current 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 (which were all non-speech) from the previous Tan and Lerner study. 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 ear con-type sounds (car horn, tire skid).

As a result of the current study, Sound #26 (“Warning, Warning, Warning”) was used for both driver interface studies (i.e., Study 2 and Study 3) which evaluated a speech alert condition. In addition, based on the current findings, Sound #8 (which corresponds to Stimuli 10 in the earlier Tan and Lerner study) was used for all three driver interfaces studies (i.e., Study 2, Study 3, and Study 4) as the non-speech alert sound. A 1/3 octave band and time series analysis of this non-speech sound can be found in the Tan and Lerner paper (see Appendix A). 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 2500 Hz and 2650 Hz peaks.

In conclusion, these results provided a sound empirical justification for the selection of the non-speech and speech sounds used in the follow-up, closed-course driver-interface studies.

Verbal Instructions Used in the Auditory Crash Alert Evaluation Procedure

The reason we have invited you here today is that we are in the process of trying to select sounds to use in vehicles that would serve as a collision warning sound. In a few minutes I am going to have you listen to a number of different sounds. Each sound you will hear is being considered as a collision warning sound. But before you listen to the sounds it is important that you understand the requirements of the sound.

To help give yourself some frame of reference, try to recall your experience at the General Motors Proving Grounds in Milford, MI this past fall. In one part of that study, your task was to brake at the last second possible using hard braking to avoid colliding with the lead car.

Now, imagine that instead of being on the test track you're driving on a real road. Further, suppose your distracted or not paying attention to your driving and you're rapidly approaching a slower or stopped vehicle. The collision warning sound would alert you to this dangerous situation. When you hear the warning sound you have to decide upon the appropriate driving action to take. The driving action required, for example braking or steering, would depend on your driving situation. And going back to what you did on the test track, if braking is the appropriate action, you would need to brake hard immediately.

So as you see, the warning sound needs to get the driver's attention while at the same time allowing the driver to respond appropriately.

In addition, it is also possible that the warning may sound in an inappropriate situation. In other words, when it is a "false" alarm. For our purposes, assume that false alarms could occur as often as once a day to once a week, depending on the driver. A false alarm could be caused by a non-threatening event such as, approaching a guard-rail or sign on a sharp curve. In this case, the collision warning system may mistake the guardrail or sign for a stopped vehicle. It would not be the case that the warning would sound periodically without any reason at all.

But because false alarms may occasionally occur, the warning sound needs to get the driver's attention without being overly annoying.

Okay, we are now ready to listen to the sounds. For each sound you hear, you will be asked to rate the extent to which you agree with a statement made about that sound. For example, consider the practice statement "This sound is very musical." You will hear a sound. Then you will rate that sound on a scale ranging from Strongly Agree to Strongly Disagree based on the extent to which you agree that the sound is very musical. And in just a moment we will go over the scale in more detail.

But before we begin I would like to stress upon you to remember that the warning sound needs to immediately get your attention and allow for an appropriate response but not be overly annoying when false alarms occur. Please keep this information in mind as you make your judgments about each sound.

Do you have any questions so far?

You are going to be listening to the sounds over these headphones. But wait just a few more moments until were done with the directions to put them on and adjust them.

During the session each one of you will be sitting with your back to the table. We are doing this primarily to keep the equipment and cords out of your way. But I should mention that the headphone cords are delicate so it would be very helpful if you are careful with them. The headphones are marked for right and left ear and you should wear them that way. One last thing, while you're listening to the sounds, try to avoid touching the outside of the earphones because that will distort the sounds.

When the tape begins, the first sound you will hear is the interior sound of the Taurus that you drove at the proving grounds traveling at 70 mph. This is the actual ambient noise that is present inside the vehicle while you are traveling. All of the test sounds have been recorded on top of the ambient noise so this noise will be continuous. You will hear the first warning sound a few seconds after the ambient noise begins. The warning sounds may at times appear strange but I am going to ask that you refrain from making any comments about them during the test.

Okay we are now ready to go through an actual practice run. The practice statement on your answer sheet is THIS SOUND IS VERY MUSICAL. As you hear each warning sound you should circle your response for that sound on the scale provided. That is, you should circle the response on the scale ranging from Strongly Agree to Strongly Disagree that reflects the extent to which you agree that the sound is very musical. You will hear each sound in sequence. After you have rated all the sounds on the first statement we will follow the same procedure for the second statement and so on. The sounds used for practice are the same sounds being tested. Any questions? Please put your headphones on now.

A20 / MODELING CAMP STUDY 1 DATA FOR CRASH ALERT TIMING PURPOSES

Background of Modeling Effort

The primary goal of the first CAMP human factors study (CAMP Study 1) was to develop a crash alert timing approach for a FCW system by exploring various driver behavior measures. In CAMP Study 1, 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. This initial step of understanding drivers' "last-second" braking behavior *without* a FCW system was the focus of CAMP Study 1.

More specifically, 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 time it takes for the driver to respond to the crash alert and begin braking (which includes *driver brake reaction time*), and the second parameter is the driver deceleration (or braking) behavior. In response to this alert across a wide variety of initial vehicle-to-vehicle kinematic conditions, this second parameter was addressed by CAMP Study 1, which is also the focus of this modeling effort.

Characterization of Database Modeled

In CAMP Study 1, under closed-course conditions, drivers were asked to make "last-second" braking judgments while approaching a slowing or stopped "surrogate" (lead vehicle) target, which is described below. Subjects experienced trials in which the lead vehicle (or *Principal Other Vehicle*) was parked (or stationary), and trials in which the Principal Other Vehicle (*POV*) was moving. These two general types of test trials will be referred to as *Stationary Trials* and *Moving Trials*, respectively. During Stationary Trials, subjects were asked to approach the parked surrogate target at an instructed speed, either 30, 45, or 60 mph. During Moving Trials, subjects followed a lead vehicle which towed the surrogate target at these same three speeds, and were given ample time to maintain and stabilize at what they considered to be their "normal" following distance. Next, the POV driver enabled the POV to automatically brake to a stop according to a prespecified braking profile, which resulted in a constant deceleration of either -0.15, -0.28, or -0.39 g's. At that point, the test participant was asked to wait to brake the *subject vehicle* (or *SV*) until the last possible moment in order to avoid colliding with the surrogate target. When both vehicles came to a complete stop, data collection was halted and the trial was ended. During Stationary Trials, subjects were asked to make these same braking judgments while approaching the parked surrogate target.

Drivers were asked to make these last second braking judgments under three different braking instruction conditions, “normal” braking, “comfortable hard” braking, and “hard” braking. Each instruction differed on the instructed braking intensity or pressure. Under one instruction, the driver was asked to brake *with normal braking intensity or pressure*. Under a second instruction (the “*comfortable hard braking”* instruction), the driver was asked to brake with *the hardest braking intensity or pressure that they felt comfortable*. Under a third instruction (the “*hard braking”* instruction), the driver was asked to brake with *hard braking intensity or pressure*. Three instruction conditions were included to provide insight into when drivers should be presented crash alert information, when drivers should not be presented crash alert information (in order to avoid in-path nuisance alerts or any tendency the driver may have to ignore an alert which does in fact signify an alarming situation), and to also explore drivers’ interpretations of “hard” braking and “comfortable hard” braking levels. That is, the use of 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.

The surrogate (lead vehicle) target was designed to mimic a real vehicle as much as possible with the constraint that it would allow for safe impacts at low impact velocities. The experimenter had access to add-on brakes and an audible crash alert. Thirty-six younger, 36 middle-aged, and 36 older drivers were tested. Eighteen males and 18 females were tested in each age group. Overall, data from over 3800 last-second braking trials were obtained. The critical need for obtaining this type of data under controlled conditions is dictated by the infrequency of near/actual rear-end crashes (and associated “black box” data), the lack of data available to support FCW system “benefits” modeling, and the inherent difficulties associated with accident reconstruction.

Study 1 Results Influential to Modeling Approach

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 too early/not too late) estimate of the assumed driver braking onset range 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 decelerating value (i.e., at the current “constant” rate of slowing).

This required deceleration measure varied with driver speed and lead vehicle deceleration rates, which is in sharp contrast to the “constant (or fixed) driver deceleration level” assumption routinely employed in FCW system warning algorithms and “benefits” modeling. It is also important to note that these required deceleration values were relatively uninfluenced by driver age or gender, which is a desirable finding from a production implementation perspective. 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.

In the modeling described below, only data from the "hard braking instruction" condition were used, for two primary reasons. First, in educating drivers how to brake (if braking is appropriate) to a FCW system crash alert, using "hard braking" terminology seems to be the most appropriate approach (whereas "comfortable hard" is relatively ambiguous). Second, driver's braking behavior during the "comfortable hard braking" instruction was heavily influenced by the order in which drivers experienced the three braking instruction conditions above (this was not true for the "hard braking" instruction).

Goals of Current Modeling Effort

The primary goal of this modeling effort was to predict "last-second", "hard braking" onsets across the wide variety of initial vehicle-to-vehicle kinematic conditions examined in CAMP Study 1 using the required deceleration value (for reasons described above). These will subsequently be referred to as the *Required Deceleration Parameter (or RDP) modeling* efforts. The results of this portion of the modeling effort were used directly for crash alert timing purposes in the subsequent three FCW system driver interface studies. The underlying assumption is that properly characterizing (i.e., modeling) the kinematic conditions surrounding these 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). The data that was used for this modeling effort included each of the following driver performance measures obtained at SV braking onset:

- Range between the driver's vehicle and lead (surrogate target) vehicle
- Speed of the driver's vehicle (or Subject Vehicle), referred to as SV speed
- Speed of the lead vehicle (or Principal Other Vehicle), referred to as POV speed
- Deceleration level of the lead vehicle (or Principal Other Vehicle), referred to as POV deceleration

It should be noted that SV braking onset was <u>not</u> defined relative to the brake switch trigger point, since it was observed that some subjects had a tendency to momentarily ride the brakes during their last-second braking decision. Instead, SV braking onset was defined as the point in time in which the vehicle actually began to slow as a result of braking. Based on a manual analysis of 10% of the entire data set, SV braking onset was defined as five 30 Hz data samples (or 165 ms) prior to SV crossing the .10 g deceleration level.

A secondary, though important, goal of this modeling effort was to explore the ability to predict these "last-second", "hard braking" onsets based on a subset of the available "raw" data described above. The results of this portion of the modeling effort were not used for crash alert timing purposes in the subsequent three FCW system driver interface studies, but instead were used to explore the consequences of a FCW system with less than an "ideal" level of knowledge of the current kinematic conditions (e.g., limited knowledge of lead vehicle deceleration rates). (This "ideal" level of knowledge was explored with the RDP modeling efforts discussed above). Two modeling attempts were made which examined a "binning" approach for the assumed lead vehicle deceleration. These will subsequently be referred to as *Binning modeling* efforts. In one attempt, it was assumed that the FCW system could discriminate whether the lead vehicle was braking higher or lower than –0.25 g's, as well as whether the lead vehicle was moving or stationary. In a second attempt, it was assumed that the FCW system could only discriminate whether the lead vehicle was moving or stationary. Finally, four modeling approaches examined crash alert timing approaches that assumed both fixed (or constant) driver deceleration rates (either 0.3 or 0.5 g's) and fixed lead vehicle deceleration rates (either 0 or -0.17 g's). These will subsequently be referred to as *Fixed modeling* efforts.

Before discussing these modeling efforts, which developed equations for predicting range values and required deceleration values at SV braking onset, a few comments about the three potential sources of variance for predicting these values are in order.

First, there are differences between braking event circumstances (e.g., SV speed, POV speed, POV deceleration), which will be called *situation variance*. Minimizing situation variance is the focus of this modeling effort.

Second, there are differences between subjects in risk-aversion, which will be called *subject variance*. Subject variance is orthogonal to situation variance and is the variance that would be accommodated by an adjustment knob for use with a FCW system. This variance reflects the consistent bias of a given subject to brake early or late relative to other subjects in the exact same kinematic situation. The proportion of total variance accounted for by subject variance was estimated before performing regressions in order to give an upper limit on the percent of variance the model should account for. This upper limit is not a mathematical limit, but a practical limit. A model that goes above that limit is suspect because it must be accounting for subject variance in addition to situation variance.

Third, there is *random variance*, either due to measurement error or due to the subject braking at a slightly different time than intended due to perceptual error. Nothing can be done about random error, except to estimate the magnitude of its contribution to the total variance.

Each of the Required Deceleration Parameter (RDP), Binning, and Fixed modeling efforts will now be discussed in turn in detail.

Required Deceleration Parameter (RDP) Modeling Efforts

There were two RDP modeling approaches explored. The first, more complicated approach, predicted (or modeled) range where the predicted required deceleration value was part of the predictor set of variables. This will subsequently be referred to as the *RDP-Range* model. The second, more straightforward approach, modeled required deceleration directly using a standard linear regression approach, and is subsequently referred to as the *RDP-Deceleration* model. Each of these two models will now be described in turn.

RDP-Range Model

The first modeling approach taken was to model required deceleration in terms of its effect on range at braking onset. That is, this model predicted required deceleration values by minimizing errors in the predicted range values, which are a function of the required deceleration values. In order to do this, the three equations linking range to required deceleration (and other variables) had to be put into the same general structure.

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 it contacts 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 braking onset range is then calculated by inputting the predicted required deceleration value into the appropriate case equation below. It should be noted that the variables need to be expressed in common measurement units (e.g., feet), which should be consistent with those used in calculating the predicted required deceleration values. In this equation, braking deceleration values are represented as negative values. In the following case equations, the following notation is used:

R = Braking Onset Range (or Distance) in feet

V_{SV} = SV velocity in feet/sec at braking onset

V_{POV} = POV velocity in feet/sec at braking onset

dec_{REQ} = required deceleration of the SV in feet/sec^2

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

<u>Case 1</u>: POV Stationary →

$$R = \frac{(V_{SV})^2}{-2*(dec_{REQ})}$$

<u>Case 2</u>: POV Moving, contact when POV is moving →

$$R = \frac{(V_{SV} - V_{POV})^2}{-2*(dec_{REQ} - dec_{POV})}$$

<u>Case 3</u>: POV Moving, contact when POV is stationary →

$$R = \frac{(V_{SV})^2}{-2*(dec_{REQ})} - \frac{(V_{POV})^2}{-2*(dec_{POV})}$$

Each of these Case equations can be fit into a more general format, referred to subsequently as the *generalized equation*, as follows:

$$R = \frac{x}{-2*(dec_{REQ} - y)} - z$$

The dec_{REQ} is predicted (or modeled), and the values for x, y, and z are determined by the Case situations above, as follows:

for Case 1: $x = V_{SV}^2$, $y = 0$, and $z = 0$.

for Case 2: $x = (V_{SV} - V_{POV})^2$, $y = dec_{POV}$, *and* $z = 0$.

for Case 3: $x = V_{SV}^2$, $y = 0$, *and* $z = ((V_{POV})^2/-2*(dec_{POV}))$.

Each hard braking onset observation (or trial) was defined as belonging to one of the three Cases described above, and the x, y, and z portions of the equations were then calculated. This left range expressed as a function of one unknown, required deceleration. The modeling process was directed at fitting an equation to predict required deceleration. The models considered were all linear with respect to required deceleration. However, when the prediction equation replaced required deceleration in the generalized equation to predict range, the function becomes nonlinear. Thus, a nonlinear fitting procedure was required to determine the best-fit model. The loss function was squared error in range. The portion of the best-fit model that predicts required deceleration is shown below. The right half of this equation can replace required deceleration in the generalized equation in order to predict range at braking onset.

$$dec_{REQ} = -2.727 + 0.897(dec_{POV}) + 2.38(\text{if POV moving}) - 0.113(V_{SV} - V_{POV})$$

The equation above accounts for 76% of the variance in *range*. (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). It is important to note that although the loss function and percent variance accounted for were calculated with respect to range, the equation itself predicts required deceleration. In this equation, braking deceleration values are represented as negative values.

Percent subject variance was estimated for the range by calculating the sum of squares for the mean of each subject across conditions. This sum of squares, expressed as a percentage of the total sum of squares (adjusted for the grand mean), gives the percentages of variance accounted for by subject differences (i.e., the extent to which there is a consistent bias of a given subject to brake early or late relative to other subjects in the exact same kinematic situation). The percent of variance accounted for by subject variance (or subject differences) was 14%. Hence, the amount of situation variance left over which could potentially be accounted for by this model was 86%. As mentioned above, the amount of situation variance actually accounted for by the RDP-Range model was 76%.

RDP-Deceleration Model

The modeling procedure for the RDP-Deceleration model followed standard linear regression techniques. The results of the RDP-Range modeling exercise were used to guide the modeling process, but not to the exclusion of other models. Fortunately, the same combination of independent variables produced the best-fit model. The coefficients are somewhat different because the loss function is given in terms of required deceleration instead of range. The equation, which accounts for 63% of the variance in *required deceleration*, is shown below. (Braking deceleration values are represented as negative values.)

$$dec_{REQ} = -5.308 + 0.685(dec_{POV}) + 2.57(\text{if POV moving}) - 0.086(V_{SV} - V_{POV})$$

Like the RDP-Range model, the right half of this equation can be entered into the generalized equation to predict range. As with the range, percent subject variance was estimated for required deceleration by calculating the sum of squares for the mean of each subject across conditions. The percent of variance accounted for by subject differences was 26%. Hence, the amount of situation variance left over which could be potentially accounted for by this model was 74%. As mentioned above, the amount of situation variance actually accounted for by RDP-Range model was 63%.

Comparison of RDP-Range & RDP-Deceleration Models

The RDP-Range and RDP-Deceleration Models are generally very similar. They are identical in structure, which, while not surprising, suggests that they are capturing variability that is consistent across somewhat different measures. The percent variance accounted for in each case cannot be directly compared (76% for the RDP-Range model versus 63% for the RDP-

Deceleration models) because the total variance is in different measures (range versus required deceleration). However, by applying the model to the data and using them both to predict both range and required deceleration, it is possible to more directly compare these two models. Table 14 shows the average residuals (i.e., the observed minus the predicted values) in range and required deceleration for the two models overall, as well as for the three general subtypes of trials. (Note that a positive number in this table implies braking was harder than predicted, and hence, a result in a conservative direction.) Not surprisingly, the RDP-Range model performs slightly better in predicting range and the RDP-Deceleration model performs slightly better in predicting required deceleration. On the other hand, both models perform reasonably (and similarly) well at predicting both variables.

Table 14 Range and Required Deceleration Residuals (Observed Minus Expected Values) for Both the RDP-Range and RDP-Deceleration Models

	RDP Range model		**RDP Deceleration**	
Trial Type	**Req. Dec. (g)**	**Range (feet)**	**Req. Dec. (g)**	**Range (feet)**
Overall	+0.005	+2	0.000	+7
Case 1 Trials	+0.025	-3	0.000	+10
Case 2 Trials	+0.009	+2	-0.013	+20
Case 3 Trials	-0.004	+3	+0.005	+1

The left-hand portion of Table 15provides average range residuals, a somewhat more intuitive measure than the required deceleration residuals to interpret, for both the RDP-Range and RDP-Deceleration Models across all POV speed/POV deceleration combinations examined in CAMP Study 1. (For a point of reference, 1 mid-size car length is about 16 feet.). The left-hand portion of Table 16 provides predicted hard braking onset ranges, once again, across all POV speed/POV deceleration combinations examined in CAMP Study 1. In this table, the delta V assumption ($V_{SV} - V_{POV}$) shown in the second column corresponds to the mean value found for the particular POV speed/POV deceleration combination. In addition, the third column in this table corresponds to the mean braking onset range found for the particular POV speed/POV deceleration combination examined in CAMP Study 1. Overall, across both models, the predicted braking onset range is within 1 mid-size car length from the observed hard braking range for about 70% of these nominal POV speed/POV deceleration combinations. Once again, as can be seen in Table 15 and Table 16, overall, both models perform very similarly at predicting braking onset range.

Another opportunity to make relative comparisons across these two models is to examine whether the predicted hard braking onset ranges are “too early” or “too late”. In this “too early/too late” analysis, a too early predicted “hard” braking onset range is defined to occur when the predicted "hard" braking onset range is greater than the observed braking onset range during the last-second, "normal braking instruction" condition. In addition, a too late predicted "hard" braking onset range is defined to occur when the predicted "hard" braking onset range is less than the observed "hard" braking range during the last-second, "hard braking instruction" condition.

Overall, the percent "too early" predicted "hard" braking onsets for the RDP-Deceleration and RDP-Range models were 5.3% and 6.4%, respectively. Overall, the percent "too late" predicted "hard" braking onsets for the RDP-Deceleration and RDP-Range models were 13.9% and 12.1%, respectively. These results correspond well to the underlying rationale for modeling the required deceleration measure explained in the Task 4-CAMP Study 1 portion of this document. Results from this too early/too late analysis are shown in the left-hand columns of Table 17 for each POV speed/POV deceleration combination examined in CAMP Study 1.

On the whole, the RDP-Deceleration and RDP-Range models are clearly very similar, with similar coefficients and similar results in terms of residuals, and the estimated "too early" and "too late" predicted hard braking onset ranges. The RDP-Deceleration model was ultimately chosen for crash alert timing purposes in the subsequent three FCW system driver interface studies for the following reasons. The first reason was that the RDP-Deceleration model tended to predict slightly later (i.e., slightly more aggressive) braking onsets under kinematic situations when the POV braked at -0.15 g's. Relative to the other more intense POV braking profiles examined (-0.28 and -0.39 g's), this braking profile may be more representative of normal lead vehicle braking intensities drivers encounter during real-world driving. It was suspected drivers were capable of braking harder than what was observed in Study 1 when the POV braked at -0.15 g's, and hence, presenting the alert slightly later under these commonly encountered conditions provided a potential way to minimize in-path nuisance alerts. A second reason for choosing the RDP-Deceleration over the RDP-Range model was the relatively more straightforward, and accessible approach used to develop the model.

Binning Modeling Efforts

Measuring POV deceleration, as well as utilizing POV deceleration information in real-time are difficult technical problems. Hence, a model that predicts required deceleration accurately without using POV deceleration knowledge would be particularly useful. Unfortunately, the Analysis of Variance results reported in Chapter 3 of this document suggest that achieving this goal may be challenging, because these results clearly indicate the strong dependence of drivers braking onsets on the POV braking profile. Nonetheless, the data were modeled in an attempt to explore the consequences of a FCW system with less than an "ideal" level of knowledge of the current kinematic conditions such as POV deceleration level.

Two modeling attempts were made which examined a (non-fixed) "binning" approach for the assumed lead vehicle deceleration. In one attempt, it was assumed that the FCW system could discriminate whether the lead vehicle was braking higher or lower than -0.25 g's, and whether or not the lead vehicle was moving or stationary. In this modeling process, the data were put into two groups. One group, the "hard" braking group, contained data in which the POV decelerations were harder than or equal to -0.25 g's. The second group, the "light" braking group, contained the remaining data, in which the POV decelerations were less than to -0.25 g's. This will subsequently be referred to as *Binning Model 1*. A stepwise regression produced the following model, which accounts for 58% of the variance in *required deceleration*.

$$dec_{REQ} = -4.681 - 4.574(\text{if hard braking}) - 1.059(\text{if POV moving}) - 0.095(V_{SV} - V_{POV})$$

In this equation, the "if hard braking" predictor variable is set to 0 if the POV is braking "light", and is set to 1 if the POV is braking "hard". It should be stressed that the relatively high amount of variance accounted for by this model (58%) is misleading, since the distinction between light and hard braking was optimized for this particular CAMP Study 1 data set. This in effect artificially inflates the amount of variance accounted for. Hence, although this modeling exercise proved interesting in light of the technical challenges in measuring POV deceleration, because of this caveat, this model will not be discussed in any further detail.

In a second "binning" modeling attempt, it was assumed that the FCW system could only discriminate whether the lead vehicle was moving or stationary. This will subsequently be referred to as *Binning Model 2*. This model simply removed the required deceleration variable from consideration. A stepwise regression produced the following model, which accounts for 23% of the variance in *required deceleration*, is as follows:

$$dec_{REQ} = -2.718 - 5.412(\text{if POV moving}) - 0.126(V_{SV} - V_{POV})$$

The left-middle portion of Table 15 provides average range residuals for Binning Model 1 and Binning Model 2 across all POV speed/POV deceleration combinations examined in CAMP Study 1. The left-middle portion of Table 16 provides predicted hard braking onset ranges for these Binning models across all POV speed/POV deceleration combinations examined in CAMP Study 1. Finally, results from the too early/too late analysis for these Binning models are shown in the left-middle portion of Table 17 for each POV speed/POV deceleration combination examined in CAMP Study 1. The most striking, although not surprising, result from these tables with respect to Binning Model 2 is the high percentage of "too early" predicted "hard" braking onsets when the POV braked at -0.39 g's, and the high percentage of "too late" responses when the POV braked at -0.15 g's.

Table 15 Average Range Residuals (Expected - Observed) in Feet for the Various Models Examined (Corresponding Standard Deviation are Shown in Parentheses) Across all POV Speed/POV Deceleration Combinations Examined in CAMP Study 1

	Model							
POV Speed / POV Deceleration Combination	**RDP-Decel. Model**	**RDP-Range Model**	**Binning Model 1**	**Binning Model 2**	**Fixed Model 1** (dec_{SV}= -.3 g, dec_{POV}= -.17g)	**Fixed Model 2** (dec_{SV}= -.3 g, dec_{POV}= 0 g)	**Fixed Model 3** (dec_{SV}= -.5 g, dec_{POV}= -.17 g)	**Fixed Model 4** (dec_{SV}= -.5 g, dec_{POV}= 0 g)
30 mph /Stat.	0 *(22)*	+19 *(22)*	+2 *(22)*	+10 *(22)*	+120 *(28)*	-7 *(22)*	-16 *(22)*	-46 *(23)*
30 mph/0.15 g	-2 *(22)*	+16 *(23)*	+2 *(23)*	-20 *(18)*	-16 *(20)*	-29 *(17)*	-30 *(17)*	-33 *(17)*
30 mph/0.28 g	-1 *(19)*	+1 *(18)*	-10 *(21)*	+1 *(19)*	-15 *(21)*	-33 *(17)*	-34 *(17)*	-39 *(17)*
30 mph/0.39 g	-8 *(18)*	-12 *(18)*	-2 *(19)*	+11 *(20)*	-15 *(21)*	-32 *(16)*	-36 *(16)*	-41 *(17)*
45 mph/Stat.	-8 *(57)*	+7 *(57)*	-7 *(57)*	-9 *(58)*	+313 *(53)*	+19 *(52)*	-1 *(53)*	-71 *(57)*
45 mph/0.15 g	-17 *(35)*	+9 *(36)*	-13 *(34)*	-44 *(32)*	-33 *(33)*	-55 *(33)*	-57 *(33)*	-62*(34)*
45 mph/0.28 g	+1 *(33)*	+1 *(30)*	+16 *(33)*	+3 *(32)*	-27 *(40)*	-58 *(29)*	-60 *(28)*	-68 *(27)*
45 mph/0.39 g	-7 *(30)*	-16 *(30)*	+6 *(31)*	+32 *(32)*	-25 *(40)*	-60 *(27)*	-63 *(27)*	-72 *(27)*
60 mph/Stat.	-23 *(62)*	-18 *(63)*	-26 *(63)*	-41 *(63)*	+56 *(77)*	+67 *(61)*	+33 *(61)*	-85 *(62)*
60 mph/0.15 g	-32 *(44)*	-7 *(45)*	-26 *(43)*	-63 *(42)*	-48 *(43)*	-74 *(41)*	-76 *(42)*	-83 *(44)*
60 mph/0.28 g	+2 *(48)*	-4 *(46)*	-31 *(47)*	+5 *(46)*	-43 *(56)*	-87 *(44)*	-90 *(43)*	-101 *(43)*
60 mph/0.39 g	+3 *(44)*	-17 *(44)*	+29 *(46)*	+68 *(48)*	-32 *(63)*	-82 *(45)*	-86 *(44)*	-99 *(44)*

Table 16 Comparison of the Mean Observed Hard Braking Onsets (which are in bolded font) to the Predicted Hard Braking Onset Ranges (in Feet) for the Various Models Examined Using the Mean Delta V's (V_{SV}–V_{POV}) Observed Across all POV Speed/POV Deceleration Combinations Examined in CAMP Study 1

			Model							
POV Speed/POV Deceleration Combination	**Delta V Assumption in mph** *(not relevant to Fixed models)*	**Mean Observed Hard Braking Onset Range for Cond.**	**RDP-Decel. Model**	**RDP-Range Model**	**Binning Model 1**	**Binning Model 2**	**Fixed Model 1** (dec_{SV}= -.3 g, dec_{POV}= -.17g)	**Fixed Model 2** (dec_{SV}= -.3 g, dec_{POV}= 0 g)	**Fixed Model 3** (dec_{SV}= -.5 g dec_{POV}= -.17 g)	**Fixed Model 4** (dec_{SV}= -.5 g dec_{POV}= 0 g)
30 mph /Stat.	29.8	***106***	106	124	116	108	228	99	90	59
30 mph/0.15 g	8.6	***39***	35	56	16	38	19	8	7	5
30 mph/0.28 g	10.4	***48***	49	49	50	36	28	12	11	7
30 mph/0.39 g	11.2	***52***	45	41	64	51	32	14	13	8
45 mph/Stat.	44.6	***205***	196	211	195	196	511	222	201	133
45 mph/0.15 g	11.4	***77***	53	80	26	56	33	14	13	9
45 mph/0.28 g	13.1	***85***	84	83	84	58	44	19	17	11
45 mph/0.39 g	14.2	***90***	84	74	120	95	52	22	20	13
60 mph/Stat.	58.0	***318***	287	293	269	284	865	375	341	225
60 mph/0.15 g	11.8	***96***	55.	83	27	59	36	16	14	9
60 mph/0.28 g	15.7	***122***	119	114	115	76	63	27	25	16
60 mph/0.39 g	16.3	***124***	121m	104	176	139	68	30	27	18

Table 17 Percent "Too Early" Hard Braking Onsets / Percent "Too Late" Predicted Hard Braking Onsets (the "Too Late" Onsets are in Bolded Font) Across all POV Speed/POV Deceleration Combinations Examined in CAMP Study 1

Definitions of "Too Early" and "Too Late" Predicted Hard Braking Onset Ranges

A *too early* predicted "hard" braking onset range is defined to occur when the predicted "hard" braking onset range is greater than the observed braking onset range during the last-second, "normal braking instruction" condition.

A *too late* predicted "hard" braking onset range is defined to occur when the predicted "hard" braking onset range is less than the observed "hard" braking range during the last-second, "hard braking instruction" condition.

	Model							
POV Speed / POV Deceleration Combination	**RDP-Decel. Model**	**RDP-Range Model**	**Binning Model 1**	**Binning Model 2**	**Fixed Model 1 (dec_{SV}= -.3 g, dec_{POV}= -.17g)**	**Fixed Model 2 (dec_{SV}= -.3 g, dec_{POV}= 0 g)**	**Fixed Model 3 (dec_{SV}= -.5 g, dec_{POV}= -.17 g)**	**Fixed Model 4 (dec_{SV}= -.5 g, dec_{POV}= 0 g)**
30 MPH /Stat.	5 / **16**	8 / **4**	5 / **10**	6 / **6**	88 / **1**	2 / **29**	0 / **38**	0 / **99**
30 MPH/0.15 g	2 / **12**	18 / **1**	2 / **11**	0 / **66**	0 / **53**	0 / **98**	0 / **99**	0 / **100**
30 MPH/0.28 g	5 / **9**	6 / **10**	19 / **28**	6 / **9**	1 / **41**	0 / **99**	0 / **99**	0 / **100**
30 MPH/0.39 g	4 / **30**	3 / **41**	7 / **20**	36 / **6**	2 / **52**	0 / **98**	0 / **98**	0 / **100**
45 MPH/Stat.	3 / **13**	5 / **8**	3 / **12**	3 / **13**	99 / **0**	8 / **7**	3 / **9**	0 / **89**
45 MPH/0.15 g	1 / **11**	7 / **3**	2 / **11**	0 / **91**	0 / **58**	0 / **100**	0 / **100**	0 / **100**
45 MPH/0.28 g	8 / **7**	8 / **6**	13 / **15**	11 / **7**	1 / **32**	0 / **93**	0 / **97**	0 / **99**
45 MPH/0.39 g	10 / **15**	5 / **25**	23 / **8**	56 / **5**	2 / **47**	0 / **99**	0 / **99**	0 / **99**
60 MPH/Stat.	1 / **22**	1 / **22**	1 / **25**	0 / **35**	100 / **0**	21 / **1**	11 / **6**	0 / **69**
60 MPH/0.15 g	0 / **19**	3 / **2**	1 / **20**	0 / **95**	0 / **64**	0 / **100**	0 / **100**	0 / **100**
60 MPH/0.28 g	6 / **5**	7 / **6**	11 / **10**	16 / **4**	0 / **24**	0 / **94**	0 / **97**	0 / **100**
60 MPH/0.39 g	20 / **10**	6 / **16**	36 / **6**	66 / **1**	3 / **38**	0 / **96**	0 / **98**	0 / **100**

Fixed Modeling Efforts

Four modeling approaches examined crash alert timing approaches that assumed both fixed (or constant) driver decelerations rates (decSV) and fixed lead vehicle (or POV) decelerations (decPOV) rates. These deceleration assumptions are characteristic of current crash alert timing approaches. The four combinations of the assumed driver deceleration and lead vehicle deceleration rates are shown below, along with the corresponding model name. It should be noted that Fixed Model 2 and Fixed Model 4 below were the working assumptions for cautionary and imminent crash alert timing as part of CAMP's initial 2-stage alert timing approach, prior to the results obtained from the CAMP Task 4 Human Factors Studies discussed in this report.

Table 18 Fixed Modeling Efforts

Model Name	**Assumed dec_{SV}**	**Assumed dec_{POV}**
Fixed Model 1	-0.30g's	-0.17g's
Fixed Model 2	-0.30g's	0 g's
Fixed Model 3	-0.50g's	-0.17g's
Fixed Model 4	-0.50g's	-0g's

These assumptions were input into the Case 2 equation discussed above, which is shown again below, to calculate the predicted hard braking onset range.

$$R = \frac{(V_{SV} - V_{POV})^2}{-2*(\, dec_{SV} - dec_{POV})}$$

The right half of Table 15 provides average range residuals for each of these Fixed models across all POV speed/POV deceleration combinations examined in CAMP Study 1. The right half of Table 16 provides predicted hard braking onset ranges for these models across all POV speed/POV deceleration combinations in CAMP Study 1. Finally, results from the too early/too late analysis for these Fixed models are shown in the right half of Table 17 for each POV speed/POV deceleration combination in CAMP Study 1. These results indicate that the predicted hard braking onsets are substantially later relative to the RDP Models discussed earlier across nearly all POV speed/POV deceleration combinations. Results from the too early/too late analysis indicate, across nearly all POV speed/POV deceleration combinations, a near total absence of "too early" predicted "hard" braking onsets, and an extremely high percentage of "too late" responses (particularly when the lead vehicle is moving).

Summary of Modeling Efforts

Together, results from these eight models clearly indicate that a great deal of predictive value is lost if lead vehicle (POV) deceleration cannot be measured. In each of the Required Deceleration Parameter (RDP) and Binning modeling efforts discussed above, POV deceleration was the first variable entered into a stepwise regression, since it accounted for the most variance.

The RDP-Deceleration model was ultimately chosen for crash alert timing purposes in the subsequent three FCW system driver interface studies. This model is distinctly different from commonly employed FCW warning algorithms used for crash alert timing approaches (as well as "benefits" modeling), which assume fixed driver deceleration rates independent of driver speed and lead vehicle deceleration rates. Under the RDP-Deceleration model, the assumed driver deceleration varies as a function of both the speed difference between the two vehicles (i.e., delta V) and lead vehicle deceleration levels. In the remainder of this report, the equation resulting from this RDP-Deceleration model will subsequently be referred to as the *CAMP RDP equation* for brevity purposes. Earlier in this appendix, this equation predicted required deceleration values in feet/second^2. The equation below provides an equivalent, perhaps more accessible, version of this equation, which predicts required deceleration in g's. In this equation, braking deceleration values are represented as negative values, and the following notation and measurement units are employed:

dec_{REQ} = required deceleration of the SV, expressed in g's (negative for braking)

dec_{POV} = deceleration level of the lead vehicle (or Principal Other Vehicle), expressed in g's

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

V_{POV} = velocity of the Principal Other Vehicle (or POV) velocity, expressed in meters/sec

("if POV moving" 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).

CAMP RDP Equation

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

On a final note, the reader should be reminded that the underlying assumption is that properly characterizing (i.e., modeling) the kinematic conditions surrounding these hard braking onsets without FCW system crash alert support (i.e., the RDP-Deceleration model) 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 eventually received strong support in the subsequent three FCW system driver interface studies, both from a driver performance and driver preference perspective. Hence, these results clearly indicate the added value obtained by gathering data under highly valid, controlled, realistic conditions involving a wide range of typical drivers braking a real car on a real road to a realistic crash threat.

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APPENDIX B

COMPUTING ALERT ONSET TIMING REQUIREMENTS

B COMPUTING ALERT ONSET TIMING REQUIREMENTS

B.1 Introduction

This appendix presents equations to compute ranges (distances) at which a forward collision warning (FCW) system needs to present crash alerts to a driver. These ranges depend on the speeds and accelerations of the FCW-equipped vehicle and another vehicle that is ahead. These equations are quite similar to those in Chapter 4, Section 4.2.3.1 (Crash Alert Timing and Crash Alert Timing Adjustability). There are differences, however, that may be significant when actually computing requirements for specific situations. These differences include:

- A precise description of the domain of validity of the equations is provided,
- The equations may be used in some non-closing situations (e.g., when the lead vehicle is accelerating), unlike those in the report body,
- A specific computation is presented to determine which kinematic "case" is expected, that is, whether the lead vehicle is expected to be stopped or moving at impact, and
- The equations handle all special cases that fall within the stated domain of validity (e.g., all divide-by-zero errors and ambiguities are eliminated).

The equations in this appendix are referenced throughout the body of the report. In Chapter 3, the alerts presented to subjects in the human factors experiments are consistent with these equations. Chapter 4 recommends alert onset timing requirements; the equations in this appendix allow one to compute the requirements for all conditions within the stated domain of validity. Because those requirements are a basis for the objective test procedures described in Chapter 5 and evaluated in Chapter 6, the equations are referenced in those chapters as well.

Note that although the computational procedure presented in this appendix could serve as a starting point for designing alert onset timing for FCWs, the algorithm is *not* required to be part of an FCW system. Furthermore, the algorithm presented in this chapter is not intended to handle all potential rear-end collision situations, nor is it intended to handle all possible operational situations. Further remarks on this subject are found later in this appendix.

Two sections follow within this appendix. First, the approach to alert onset timing requirements presented in Chapter 4 is reviewed. Second, the algorithm is presented and limits of the validity of the equation are described.

B.2 Review of Approach to Alert Onset Timing Requirements

Chapter 4 describes the circumstances in which FCW alerts are required, allowed, or not allowed. Many factors are considered in this determination, including aspects of the SV's motion, the presence of a potentially threatening object and its characteristics, and the relative positions and motion between the SV and the threat. (See Chapter 4 for a complete description of requirements.) In this appendix, however, assume that all conditions are such that determining whether an alert is required, prohibited, or is allowed, depends only on the alert onset timing – that is, the longitudinal distance between the vehicles and their speeds and accelerations.

The approach to minimum requirements for alert onset timing that is presented in Chapter 4 requires that the onset of FCW crash alerts occurs with a timing that is neither "too early" nor "too late," given the existing speeds and accelerations of the vehicles. A key finding in the first human factors study in Chapter 3 is that the timing of drivers' decisions to begin last-moment braking can be modeled well by considering the deceleration required to avoid impact. Since a driver requires a finite time to perceive the alert, react, and finally press the brake pedal, it follows that a valid approach to last-moment alerts is one in which an alert is given at the last moment possible to account both for the driver reaction time and the distance that the driver's vehicle closes on the lead vehicle before the driver can bring the vehicle's speed down to that of the lead vehicle.

The requirement specifications of "too early" and "too late" are each expressed using an alert range that is computed using the two vehicles' speeds and the accelerations. The same set of equations is used to compute the two bounds, however, a pair of parameters within the equations is assigned one set of values for "too early" and another set for "too late." Consider a lead vehicle – a "principal other vehicle" (POV) – and a following "subject vehicle" (SV) which is equipped with an FCW system. The two specifications each correspond to the minimum range at which an alert would be required to bring the SV speed down to the POV's speed with no range remaining (just touching bumpers) under the following assumptions:

- SV braking would begin only after a known delay time after the alert onset.
- SV braking (after the delay) may be modeled as a constant acceleration value that may depend on vehicle speeds and acceleration values at the time of alert onset.
- The minimum range considers the POV's acceleration at the time of alert onset, and assumes that the POV acceleration will remain constant throughout the event, unless the POV comes to a stop (in which case the POV is assumed to remain at rest).

Up to this point, the approach stated above is not new to this project. The unique aspect of the timing approach suggested in this report is that the parameters used to describe the delay time and the SV braking level is based on the human factors experiments (as described in Chapter 4 and elaborated on later in this appendix).

Those experiments:

1. Demonstrated that the general timing approach is consistent with a model of last-second braking decisions by drivers without an FCW.

2. Generated sets of parameters that can be used in the equations that yield alert timing that is simultaneously timely and not annoying (the parameters describe driver braking reaction times and braking levels).

3. Demonstrated driver acceptance and acceptable performance, given alert timings with such an approach.

B.3 Equations to Compute Alert Timing Requirements

The approach to alert onset timing requirements is based on observed braking decisions of drivers, as described in Study 1 of Chapter 3. To compute numerical values for the alert requirements for a given situation, however, requires using a set of equations that may appear somewhat lengthy, and that become more complicated as more sets of initial conditions are addressed. The straightforward application of the simple kinematics and the simple model of driver response to alerts require handling many possible "cases" of initial, intermediate, and final kinematic states. The number of cases that is to be handled is familiar to any designer or analyst that has translated the simple timing approach above into a warning algorithm, and tested the algorithm either in simulation or in a vehicle. The inclusion of the new driver response parameters does not significantly complicate the computations.

This section presents a set of equations that should be used to evaluate the alert onset timing of an FCW being evaluated with the vehicle-level objective test procedures described in Chapter 5. The equations provide the "too early" and "too late" alert onset ranges for any given set of vehicles speeds and accelerations that fall within the limited set of initial conditions described. This set of initial conditions includes those that will occur at or near alert onset in the objective test procedures. These equations do *not* constitute a complete warning algorithm and should not be used as such. Although the equations also provide suitable alert timing for many common potential rear-end crash situations – including the conditions seen both in the human factors experiments and in the objective test procedures of Chapter 5 – there will be other potential rear-end crash situations in which a more complete set of equations is needed. In addition, the equations in this appendix do not include additional logic used to handle situations in which the driver is already braking the host vehicle.

B.3.1 Equations to Compute Alert Timing Requirements

The requirements are valid over a restricted domain of initial conditions. This domain of validity is now presented. Let V_{SV} and V_{POV} denote the initial speeds of the SV and the POV, respectively, as shown in Figure 1. Let dec_{SV} and dec_{POV} be the initial decelerations of the SV and the POV, respectively (negative values for braking). Let "Delay Time" denote the total delay time between the crash alert onset and when the driver decelerates the vehicle in response to the crash alert. The total delay time includes both the driver's reaction time and the nominal brake system lag. The driver's deceleration response is denoted dec_{SVR}, and this is negative for braking. The equations address the computation of the alert requirements; the following conditions are assumed:

- SV speed is initially at least 16 kph.
- POV speed is positive or zero, but is not negative.
- SV speed is expected to be greater than the POV speed at the end of the total delay time.
- SV acceleration at crash alert onset has an absolute magnitude that is no greater than 0.1g. This should hold during nearly all normal non-braking driving conditions.
- SV speed is not expected to go to zero during the delay.
- If the POV is initially moving, it will not come to rest during the delay.
- The POV is either decelerating or not accelerating more than 0.08g.

If any of these conditions do not hold, the equations that follow are not applicable for computing the requirements for alert timing.

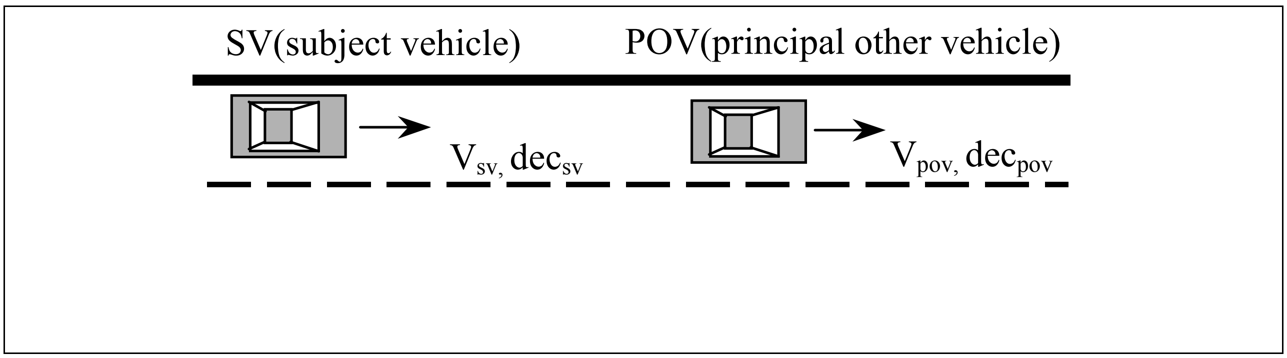

Figure 1 Initial Situation of Vehicle Pair

To compute alert requirements, four steps are suggested.

1. Project values for the speeds from the initial conditions to the end of the total delay time. The predicted speeds at the time of SV deceleration onset are:

$$V_{SVP} = V_{SV} + dec_{SV}\text{*Delay Time}$$

$$V_{POVP} = V_{POV} + dec_{POV}\text{*Delay Time}$$

2. Evaluate the expected driver braking response, dec_{SVR}, and the total delay time. As described in Chapter 4, the total delay time should be the sum of the assumed driver reaction time, plus an 0.200 sec value that represents a typical delay time between a rapid brake pedal application and deceleration of the vehicle. Chapter 4 states that to compute the minimum range at which the alert can begin, one should use a driver reaction time of 1.18 sec and a driver braking level

described by the CAMP ADP equation (the predicted values for speeds are to be used in the ADP equation):

Delay Time = 1.18 + 0.20 = 1.38 sec.

dec_{SVR} (g's)= -0.260g –(0.00725g/m/s)V_{SVP}

To compute the maximum range at which the alert may begin (for the minimum FCW setting), Chapter 4 states that a driver reaction time of 1.52 should be used, along with the CAMP RDP equation (with predicted speed values):

Delay Time = 1.52 + 0.20 = 1.72 sec.

dec_{SVR} (g's)=-0.165g+(0.685g/g)*dec_{POV}*(dec_{POV}<0)*(V_{POVP}>0)

+0.080g*(V_{POVP}>0) +(-0.00877g/m/s)*(V_{SVP} – V_{POVP})

The conditional expressions in the equation above should be evaluated as one if the inequality is true, and evaluated to zero if it is false. For instance, the second term above includes two conditional expressions so that the term (0.685g/g)*dec_{POV} is included only if the POV will be both moving and decelerating after the total delay time.

3. Compute the minimum range at which an alert would be needed so that the model of driver response would just bring the closing speed to zero as the range went to zero. (Derivations of the following equations are not presented. The equations follow from a straightforward application of kinematics using the simple models presented, and assuming the conditions above apply.)

The alert range, R, is the sum of the desired range at SV deceleration onset ("braking onset range," or BOR), plus the amount that the range will decrease during the total delay time ("delay time range," or DTR). The delay time range is

DTR = (V_{SV} – V_{POV})*Delay Time + 0.5*(dec_{SV} – dec_{POV})*(Delay Time)^2

Brake onset range can be computed using one of two possible expressions. These correspond to whether the POV is expected to be moving or stopped when the "contact" occurs (contact is the moment at which the models predict the range rate and range both go to zero). The following conditional determines which of these two cases is expected:

If dec_{POV}*V_{SV} <= dec_{SVR}*V_{POV} – dec_{POV}*Delay Time*(dec_{SV} – dec_{SVR}),

Contact expected when POV is stopped (Case 3 in Chapter 4, Section 4.2.3.1)

Else,

Contact expected when POV is moving (Case 2 in Chapter 4, Section 4.2.3.1)

This inequality is based on a simpler equation that compares the expected stopping time for the POV with the sum of the total delay time and the expected stopping time of the SV. It was necessary to rearrange the inequality so it provides the correct answer (true/false) even when POV speed and/or POV acceleration is zero.

Contact with a stopped POV includes cases in which the POV is initially stopped as well as cases in which the POV decelerates to a stop during the SV's braking maneuver. In this case, the braking onset range BOR is the difference between the SV's expected stopping distance and the POV's expected stopping distance:

If $dec_{POV} = 0$,

$$BOR = (V_{SVP})^2/(-2*dec_{SVR})$$

Else,

$$BOR = (V_{SVP})^2/(-2*dec_{SVR}) - (V_{POVP})^2/(-2*dec_{POV})$$

The case in which contact is expected when the POV is moving includes cases in which the POV is not decelerating, and in fact is accelerating within the conditions assumed earlier. It also includes cases in which the POV is decelerating, but conditions are such that contact is still expected before the SV deceleration can occur quickly enough. One common situation leading to this case is when the SV is tailgating at higher speeds and the POV begins braking at significant levels. If contact is expected when the POV is moving the braking onset range is:

$$BOR = (V_{SVP} - V_{POVP})^2/(-2*(dec_{SVR} - dec_{POV})).$$

Regardless of which braking onset range equation is used, the alert onset range R is to be computed using:

$$R = BOR + DTR.$$

4. Apply other applicable requirements that may affect requirements of the range at alert onset (Chapter 4, Section 4.7). For example, if the first three steps above yield a maximum range ("too late" cut-off) that is greater than the maximum longitudinal extent of the alert zone (100 meters), then the "too late" cut-off is adjusted to this value. The reader is advised to be familiar with all requirements of Chapter 4, Section 4.7, which puts these computational procedures into context.

APPENDIX C

ANALYSIS OF FORWARD COLLISION WARNING PERFORMANCE METRICS USING REAMACS

TABLE OF CONTENTS

List of Tables

List of Figures

C ANALYSIS OF FORWARD COLLISION WARNING PERFORMANCE METRICS USING REAMACS

C.1 Foreword

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 in 1997, early in the project, and made use of the best available information at the time. 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.

- Because the modeling work was completed early in the project, the reader should keep in mind the following while reading:
- In this document, “cautionary” and “imminent” alert warning algorithms refer to two specific warning algorithms. These are both based on closing speed, and were assumed to be candidates for specifying alert onset requirements for a single-stage alert. “Imminent” alert does *not* correspond to the proposed alert onset timing requirements of Chapter 4, nor does “cautionary.”
- The alert onset timing requirements proposed in Chapter 4 are not specifically included in this appendix’s analysis. These requirements were developed in the final stages of the project and a re-computation of these results is outside the project scope. The algorithm closest to the type of timing requirements suggested in Chapter 4 may be the “lead vehicle deceleration” algorithm with a parameter set “RT=1.5 sec, asv = -0.3g”.

C.2 Summary of Findings

This document reports modeling and simulation work that estimates performance measures of Forward Collision Warning (FCW) systems.

This work studies relative performance effects of warning algorithm types, maximum warning ranges, and sensitivity to modeling assumptions. Warning algorithms considered include a first (earlier) alert, the “cautionary” crash alert, and a second set of parameters to define a second (last-moment) alert, termed the “imminent” crash alert. Performance metrics are computed here for a FCW that issues *single* alerts based on various warning algorithms, including the cautionary and imminent crash alerts as well as basic variants of these designs. Also included are warning algorithms that make use of lead vehicle deceleration information.

The metrics used to compare performance of countermeasures are the potential to reduce relative harm, and the relative frequency of in-path nuisance alerts. Relative harm is computed over a set of potential rear-end crash scenarios; relative harm is defined as the ratio of the sum of squared impact speeds in crashes with vehicles equipped with a FCW system to the same metric computed for vehicles not equipped with a FCW. In-path nuisance alerts are alerts triggered by vehicles in the path of the host vehicle in situations that the driver does not regard as alarming. The modeling work assumes perfect sensing by the FCW system and 100% compliance of drivers to warnings. It is argued, however, that to understand the likely benefit of FCWs in practice, future work is needed to consider the possible effects that nuisance alerts may have on reducing driver usage and compliance with the crash warning system. This report does not attempt to include these effects and reduction in harm and in-path nuisance alerts rates are computed separately.

The modeling work here builds on a simulation tool named REAMACS, which has been developed and used at Ford since 1993. REAMACS is an acronym for Rear-end Accident Model and Countermeasure Simulation. Simulation results are based on rear-end crash scenarios generated using a database of actual vehicle pair speeds and headways collected from Interstate 40 near Albuquerque by the Federal Highway Administration (FHWA). This is the only comprehensive database available to CAMP at this time, and it is not known to what degree the reliance on this database has biased the simulation results. The database was generated using loop detectors, and thus leads to a simulation crash set with a significant under-representation of rear-end crashes in which the lead vehicle is stopped when struck. Also, the database is highway data and therefore may not represent vehicle pair behaviors characteristic of other roadway types.

Simulation work findings include:

1. A target sensor that can support warnings at a 75-meter range provides 93% of the benefits of a sensor with unlimited range. A more accurate representation of stopped lead vehicle situations, however, might indicate that there are benefits of a longer working range.

2. There is a potential for FCWs to reduce relative harm by up to 67 percent using the cautionary crash alert as the only warning, along with a sensor that supports a 75 meter warning range. When used as the only warning, the imminent crash alert has a potential to reduce relative harm by only 20% – this alert occurs too late for much benefit with decelerating lead vehicles. Effectiveness estimates may decrease when considering the effects of nuisance alerts on driver usage of, and compliance with, FCWs.

   When lead vehicle information is considered, there is a potential to reduce relative harm up to 81% using a set of algorithm parameters corresponding to both the cautionary and imminent parameters, and a sensor that supports a 75 m warning range.

3. Estimates of the expected exposure of a driver to in-path nuisance alerts are sensitive to modeling assumptions regarding braking levels that drivers are comfortable using in situations they consider non-alarming. For the cautionary crash alert design, a

rough scaling analysis estimates that 28 in-path nuisance alerts would occur for every rear-end crash with an impact speed of ten miles per hour or greater. This scales to one in-path nuisance alert per 4.2 years per vehicle. The imminent crash alert design leads to only 1.3 in-path nuisance alerts per rear-end crash with at least a ten mile per hour impact speed. This illustrates a tradeoff between increasing the potential to reduce relative harm and reducing the estimated in-path nuisance rates. Future experimental work is needed to allow more accurate scaling from in-path nuisance alert rates computed in simulation to rates likely to be seen in practice. Thus in-path nuisance alert results should be used only for comparison between countermeasure designs.

4. The simulation work suggests that information about a lead vehicle's deceleration level can improve the performance of a FCW system. By adding lead vehicle information to the imminent crash alert, the potential for reduction in relative harm increases from 20% to 81%, however, the corresponding in-path nuisance alert rate increases from 1.3 to 13.5 per rear-end crash with impact speed of ten miles per hour or more. By adding both lead vehicle deceleration information and varying the warning algorithm design, a potential reduction in relative harm nearly equal to that of the cautionary crash alert can be achieved (79%). While the in-path nuisance rate drops from 28 to 2.3 alerts per rear-end collision with impact speed of ten miles per hour or greater.

In practice, in-path nuisance alert rates may be different than reported here for warning algorithms that use lead vehicle deceleration information. There are two reasons. First, this work studies a particular class of such warning algorithms, which is those algorithms that assume the lead vehicle will continue braking at its current deceleration until it stops. The simulated situations, however, match this same scenario – the lead vehicle brakes completely to a stop. In practice, many nuisance alerts will occur for these algorithms when the lead vehicle brakes only momentarily, and so the in-path nuisance rate is likely to be higher in practice for this set of algorithms. Second, warning algorithms can use different assumptions about the future braking levels of the lead vehicle. These other algorithms are not studied here.

The 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. This conclusion is based on a proposed model that defines alarming situations by the braking levels necessary to avoid a collision. Results of the ongoing human factors experiments portion of this Project will provide a sounder basis for such models, and may affect the conclusion.

There is a lack of comprehensive field data on actual vehicle-following and braking behavior. More data is needed to improve confidence in predictions of potential benefits of FCW deployment.

C.3 Introduction

This study was produced as part of the Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems Project, which is a cooperative effort between the Ford/General Motors Crash Avoidance Metrics Partnership (CAMP) and the National Highway Traffic Safety Administration (NHTSA). The purpose of this project is to accelerate the implementation of automotive rear-end crash avoidance countermeasures [1]. The main purpose of the modeling and simulation work reported in this document is to support the definition of functional requirements for forward collision warning systems (FCWs).

The work reported here uses two primary metrics associated with rear-end countermeasure performance. The first primary metric is the *potential reduction in relative harm* that FCWs may provide. Relative harm is computed over a set of potential rear-end crash scenarios; relative harm is defined as the ratio of the sum of squared impact speeds in crashes with vehicles equipped with a FCW system to the same metric computed for vehicles not equipped with a FCW. Consider a "subject vehicle" (SV) which is following another vehicle, which will be called the "principal other vehicle" (POV). Let V_{sv} and V_{pov} denote the speeds of the SV and the POV, respectively, as shown in Figure 1, so that if a rear-end collision occurs, the impact speed is $V_{sv} - V_{pov}$. The terms "subject vehicle" (SV) and "following vehicle" could be used interchangeably, but this report uses "SV". Likewise, the terms "principal other vehicle" (POV) and "lead vehicle" could be used interchangeably, but again, this report uses "POV."

Let A denote a set of potential rear-end crash scenarios. Then the relative harm associated with a particular FCW can be expressed as:

$$\text{Relative Harm} = \frac{\sum_{A}(V_{sv} - V_{pov})^2 \text{ with FCW}}{\sum_{A}(V_{sv} - V_{pov})^2 \text{ without FCW}} \; X \; 100\%$$

The reduction in relative harm associated with a countermeasure or algorithm is expressed as a percent reduction in relative harm:

$$\text{Reduction in Relative Harm} = 100\% \; - \; \text{Relative Harm}$$

The potential for reduction in relative harm for an effective countermeasure is then between 0% (no effect) and 100% (all crashes eliminated). The word *potential* is a qualifier to indicate

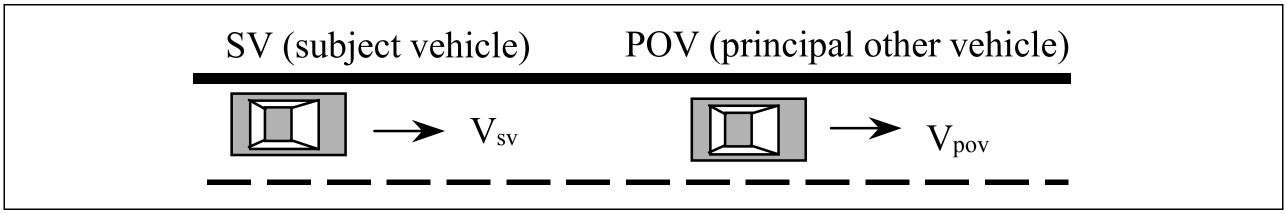

Figure 1 Vehicle Pair Illustration

that the reductions in harm conveyed by the simulation results are only provisional and that realizable reductions in harm depend on many operational and psychological factors not considered here. The potential for reduction in relative harm is used to make relative comparisons between different countermeasure designs, and is intended to provide insight into how different countermeasures might impact actual harm occurring in real-world collisions. Reduction in the number of crashes is also reported in this document since some researchers use this metric instead of harm.

The second primary metric is the *relative frequency of in-path nuisance alerts* that may result from use of FCWs. For this report, an in-path nuisance alert is defined as an alert issued by a FCW in response to a POV located in the host vehicle's path, but issued in a situation considered by the driver to be non-alarming. In-path nuisance alerts are likely to occur for any FCW since the countermeasure must issue alerts in time for an inattentive driver to take preventive action, and countermeasures currently cannot distinguish between drivers unaware of impending danger and drivers aware of the situation.

The results for potential reduction in relative harm reported in this document do not take into account the possible effect of nuisance alerts on the willingness of drivers to heed the warnings or even to use the system. Therefore the results reported here are only a first-order estimate of benefits, and may be an upper bound on the actual benefits that may occur with deployment. A key premise of CAMP, is the *realizable reduction in relative harm;* that would result from the deployment of FCWs, would depend not only on the apparent benefits, but also on the possible effect of nuisance alerts, on the willingness of drivers to use a FCW and heed the warnings. The benefits accrued when considering this effect might be called "second-order" benefits.

Figure 2 illustrates the concept of factoring in-path nuisance alerts into estimates of realizable reductions in harm. The solid line in the figure represents the estimates made in this report, as well as in similar work by others – the potential for reduction in relative harm is computed assuming ideal compliance and 100% use of FCWs. This apparent reduction in relative harm can be made to increase by changing warning algorithm design to provide

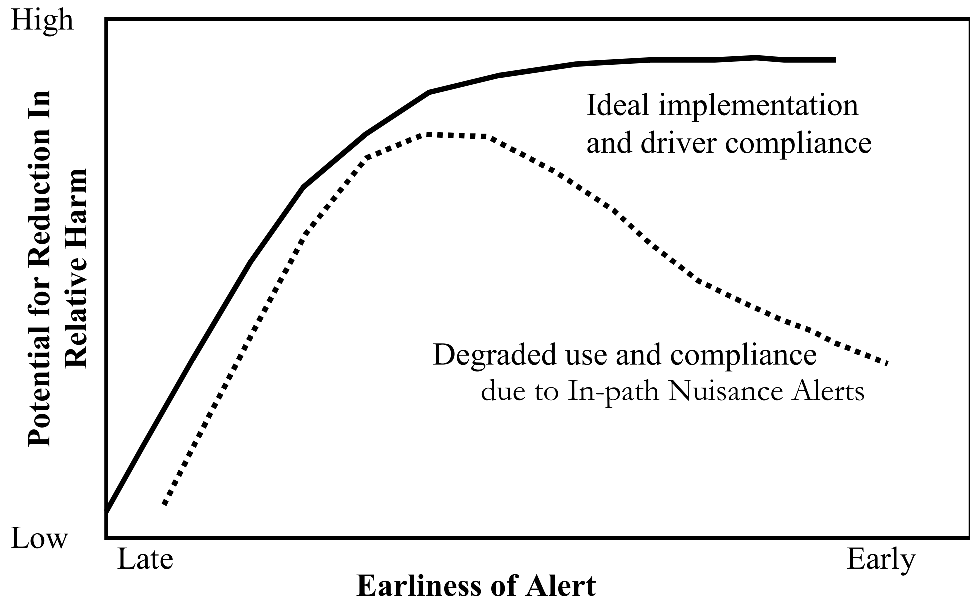

Figure 2 Possible Effect of FCW In-Path Nuisance Alerts in Reducing Realizable Reductions in Harm

earlier alerts. With earlier alerts, in-path nuisances will tend to increase, perhaps discouraging drivers from using the system and/or complying with warnings. The effects of nuisance alerts on overall system effectiveness are not well understood; one possible effect is illustrated in Figure 3, in which usage and compliance of a FCW is shown to decrease with earliness of the alert. To compute a realizable reduction in harm, the nuisance alerts must be factored into the assumed levels of deployment, usage, and compliance. The dotted line in Figure 2 illustrates the net realizable reduction in relative harm that would result if nuisance alert effects like that shown in Figure 3 are considered. This estimation of second-order benefits is not completed in this report. The first-order results reported do provide information, however, that may be used with the results of the human factors studies currently underway to estimate a realizable reduction in harm.

The simulation results reported here are based on the use of REAMACS (Rear-end Accident Model and Countermeasure Simulation). REAMACS uses headway and vehicle speed field data, processed with experimentally based models, to generate a set of vehicle

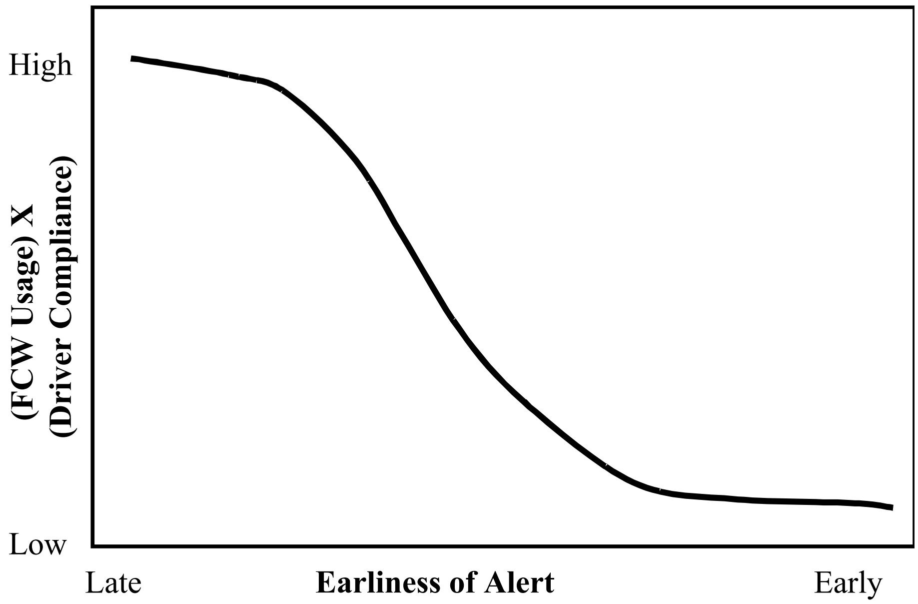

Figure 3 Concept: In-Path Nuisances May Reduce FCW Usage

pairs with potential to become rear-end collisions. Actual vehicle pair speed and headways collected from Interstate 40 near Albuquerque by the Federal Highway Administration (FHWA) are used as initial conditions for vehicle pairs. Computer simulation introduces POV braking for each vehicle pair from the database, and statistical distributions of SV driver reaction time and POV braking level are used to evaluate the outcome of the scenario. The effectiveness of a collision warning can then be estimated. The modeling work assumes perfect sensing by the FCW system and 100% compliance of drivers to warnings. By studying the variation of performance for different rear-end collision warning algorithms, algorithm parameters, and target sensing ranges, insight is gained into practical design issues as well as higher level issues of technical feasibility and upper bounds of possible deployment benefits. The modeling approach continues work on REAMACS by Farber and colleagues at Ford [2][3][4][5][6][7]. This earlier work and other studies [8][9] have contributed first-order estimates of the potential reduction of relative harm from use of FCWs. The present document contributes a definition of in-path nuisance alerts, and develops a method to estimate in-path nuisance alerts, thereby providing information for possible estimation later of second-order benefits.

The exclusive use of the FHWA database in generating vehicle pair conflict situations introduces two important caveats into any interpretation of the simulation results. First, while the database is the only comprehensive database available to CAMP at the time of these analyses, the database is generated using loop detectors, and thus no vehicle acceleration data is available. With REAMACS, then, this leads to a simulation crash set with a significant under-representation of rear-end crashes in which the POV is stopped when struck. With REAMACS about one in three or four “crashes” include a POV which is stationary when struck. Reference [10] estimates that 67% of police reported rear-end crashes in the U.S. include stationary POVs. Second, the database is highway data and therefore does not represent vehicle pair characteristics of other roadway types.

Another caveat on the results is that the in-path nuisance alerts studied here are just one type of unnecessary alert. Many types of unnecessary alerts are likely to occur with FCW deployment. Out-of-path nuisance alerts are common in today's systems. For example, an overhead bridge may fool a radar system, or a laser radar system may interpret a roadside sign on a curve as a vehicle. False alarms may also occur for other reasons including as sensor noise or cross-talk with other FCWs. The frequency of these sensor and sensing-interpretation errors may diminish as sensor technology and sensor processing algorithms develop. In-path nuisance alerts are likely to remain, though, since FCWs cannot distinguish between drivers unaware of possible danger and drivers already aware of the situation, and alert timing must always account for the perception-reaction time delay of an inattentive driver. What makes FCW feasible is the fact that vehicles are capable of much higher levels of braking than the discretionary levels of braking used by alert drivers. This makes it possible to delay a warning well beyond the point at which most alert drivers would normally begin to brake.

Major findings include:

1. A target sensor that can support warnings at a 75 meter range provides 94% of the benefits of a sensor with unlimited range. With a more accurate representation of stopped POV situations, however, a longer working range may be beneficial.

2. There is a potential for FCWs to reduce relative harm by up to 67 percent in FCW-equipped vehicles using the cautionary crash alert and an error-free sensor supporting a 75 meter warning range. When used as the only warning, the imminent crash alert has a potential to reduce relative harm by only 20% – this alert occurs too late for much benefit with decelerating POVs.

   When lead vehicle information is considered, there is a potential to reduce relative harm up to 81% using a set of algorithm parameters corresponding to both the cautionary and imminent parameters, and a sensor that supports a 75 m warning range.

3. Estimates of the expected exposure of a driver to in-path nuisance alerts are sensitive to modeling assumptions regarding braking levels that drivers are comfortable using in situations they consider non-alarming. Also, in-path nuisance alert rates estimated in this report are likely to be low, since simulation work here assumes all POVs brake to a stop, while in reality many, if not most, nuisances will occur when POVs brake only momentarily. For the cautionary crash alert design considered , a rough scaling analysis estimates that 28 in-path nuisance alerts for every rear-end crash with an impact speed of ten miles per hour or greater. This scales to one in-path nuisance alert per 4.2 years. The imminent crash alert design leads to only 1.3 in-path nuisance alerts per rear-end crash with at least a ten mile per hour impact speed. Future experimental studies are needed to provide more reliable scaling factors to use simulation results to predict real-world experience.

4. Simulation suggests that use of information about POV deceleration by a rear-end collision warning algorithm has the potential to improve FCW performance. This includes a possible increase in the potential reduction in harm as well as an easing of

the need to tradeoff between reducing relative harm and increasing the in-path nuisance alert rate. By adding POV deceleration information to the imminent crash alert, the potential for reduction in relative harm increases from 20% to 81%, however, the corresponding in-path nuisance alert rate increases from 1.3 to 13.5 per rear-end crash with impact speed of ten miles per hour or more. By adding both POV deceleration information and varying the warning algorithm design, a potential reduction in relative harm nearly equal to that of the cautionary crash alert can be achieved. (79%). While the in-path nuisance rate drops from 28 to 2.3 alerts per rear-end collision with impact speed of ten miles per hour or greater.

In practice, in-path nuisance alert rates may be different than reported here for warning algorithms that use lead vehicle deceleration information. There are two reasons. First, this work studies a particular class of such warning algorithms, which is those algorithms that assume the lead vehicle will continue braking at its current deceleration until it stops. The simulated situations, however, match this same scenario – the lead vehicle brakes completely to a stop. In practice, many nuisance alerts will occur for these algorithms when the lead vehicle brakes only momentarily, and so the in-path nuisance rate is likely to be higher in practice for this set of algorithms. Second, warning algorithms can use different assumptions about the future braking levels of the lead vehicle. These other algorithms are not studied here.

5. The 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. This conclusion is based on a proposed model that defines alarming situations by the braking levels necessary to avoid a collision. Results of the ongoing human factors experiments portion of this Project will provide a sounder basis for such models, and may affect the conclusion.

6. There is a lack of comprehensive field data on actual vehicle-following and braking behavior. More data is needed to improve confidence in predictions of potential benefits of FCW deployment.

These conclusions are drawn from simulation studies. To map these results into predictions of actual deployment results, the reader must consider the correspondence of the assumptions used in the analyses with actual traffic situations and driver behavior in the real world.

The remainder of the document is as follows. Section C.4 describes the modeling and simulation components. Section C.5 presents the two warning algorithm designs that are studied; three sets of parameters are also introduced. Section C.6 presents results of the potential reduction in relative harm for the two warning algorithms and several sensing ranges. Section C.7 describes a simulation tool that is derived from REAMACS and used to estimate the frequency of in-path nuisance alerts that accompany FCW deployment. That section also contains simulation results for in-path nuisance rates, as well as discussions of the combined harm-reduction and nuisance rate findings. Section C.8 presents a set of studies exploring the sensitivity of the results to the database set and two model parameters. Section C.9 summarizes findings.

C.4 Estimating the Potential Reduction in Relative Harm

A FCW installed on a host “subject vehicle” (SV) should issue warnings if a lead vehicle – the “principal other vehicle” (POV) – is in an “Alert Zone” and is also at a distance less than a specified range. One option for computing this specified range is to use the instantaneous difference in vehicle speeds – the closing speed – and two parameters which can be interpreted as parameters of a model of the expected reaction by a driver to an alert. Another option is to factor in knowledge of lead vehicle deceleration to improve the timeliness. In support of developing minimum functional requirements for FCW systems, the simulation work here estimates the potential for reducing relative harm that is possible for different collision warning algorithms, each with three different parameter sets, as well as sensing ranges of 20 to 300 meters.

Two specific warning algorithms are given names here: an earlier “cautionary crash alert” and a later “imminent crash alert”; the difference between the two alert timings being the numerical values of the two parameters. Both the cautionary crash alert and imminent crash alert are studied in this report, and they are studied separately, as single-alert systems. Four other alert designs are studied as well; more details of the crash warning algorithms and parameter sets are provided in Section C.5. Studying these alerts in a single-alert context is a start, and can make use of the literature on perception-reaction times to single events.

This report does not consider the effects of an adaptive cruise control system on the performance of the FCW. This work is possible, but is outside of the scope of the Project.

The modeling and simulation in this report consists of several components: the FHWA database of vehicle pair headway and speeds; the simulation tool REAMACS; a set of warning algorithms and associated parameter sets and a set of possible sensor ranges; and discussions that address how the simulation results may relate to FCW effectiveness in the real world. These components are addressed in the following sections.

C.4.1 FHWA Database

The vehicle pair database is a FHWA database generated using a pair of loop detectors on Interstate I-40 in Albuquerque, New Mexico. Two days of data were collected, each representing about 35,000 vehicle pairs. The data for each vehicle pair in the database includes each vehicle's speed, time headway, following distance, time interval, time of day, average traffic flow, and the mean speed of vehicles over a relatively long time period. The loop detectors provide no information regarding either vehicle’s acceleration. REAMACS does not use time of day, flow, or mean speed. Figure 4 shows the data collected for three vehicle pairs, as an example. The September 25, 1991 data was used for the work in this report; Section 0 looks at the sensitivity of results to using the second day of data (July 11, 1993).

Lane	Veh 1 Speed (mph	Veh 2 Speed (mph)	Headway (sec)	Follow Distance (ft)	Interval (sec)	Time (hr)	Flow	Mean Speed (mph)
1	98.643	70.765	59.902	4238.978	-27.877	5	8	76.20
1	70.765	73.703	4.433	326.707	2.937	5	8	76.20
1	73.703	70.765	14.005	991.044	-2.937	5	8	76.20

Figure 4 Excerpt from FHWA Database

C.4.2 REAMACS Approach

REAMACS is an acronym for "Rear-end Accident Modeling and Countermeasure Simulation." REAMACS is a quasi-Monte Carlo simulation tool designed to estimate the possible efficacy of rear-end collision warning (FCW) and/or adaptive cruise control (ACC) systems in helping drivers avoid or mitigate rear-end crashes [2][3][4][5][6][7]. For this work and for previously published work with REAMACS, the FHWA database of actual vehicle pair speeds and headways is used to provide initial conditions for generating potential crash scenarios. REAMACS then applies a POV deceleration and a driver reaction to that braking event. Those scenarios which are found to be potential rear-end situations are re-simulated using a countermeasure in parallel with the driver's reaction to the POV braking. Comparison of the outcomes between the driver-alone simulation and the driver-plus-countermeasure simulation provides an estimate on the potential for relative harm reduction. This comparison, in this report, is valid under *ideal* circumstances of countermeasure design and implementation, usage, and driver compliance. The phrase "potential for reduction in harm" in this report carries with it all the assumptions of this ideal setting; these assumptions are stated throughout the report.

The work reported here adds to previous results in the following ways. First, for estimates of potential reduction in harm, this report examines the specific warning properties of several algorithms. This includes warning algorithm parameter sets, which are not considered by earlier REAMACS reports. Second, minor revisions in the code improve the random distribution sampling and add a 1.2 second time delay to the warning algorithm which uses POV deceleration. Third, and most importantly, an approach to estimating the frequency of in-path nuisance alerts has been proposed and used to generate estimates of how often drivers will encounter alerts, especially those they will consider "nuisances," during operations with a FCW-equipped vehicle. This is described in Section C.7.

The potential for reduction in harm that is computed here is based on SVs equipped with FCW systems which always identify appropriate targets, and issue warnings exactly as intended, except for limits on the sensing range and time delays between sensing and computation. Out-of-path effects are not treated here. All vehicle pairs treated consist of two vehicles traveling in the same lane, and the only evasive maneuver treated is braking. No effects of driver compliance changes due to nuisance alerts are included; there is scant literature for modeling how drivers may not accept, not use, or not obey FCW systems.

The models and simulation logic used to compute reduction in harm estimates are generally identical to recent work by Farber and colleagues, with differences noted where appropriate. The first run-through of database vehicle pairs is to generate potential rear-end crash scenarios. When information on a vehicle pair is read from the database, the first step is to reject data that includes very unlikely spacing and relative speeds, such as that resulting from occasional trailer configurations that were not screened out during database generation. Vehicle pair data is rejected if the following distance is less than 4.6m, or if a deceleration of more than 0.30g by the following vehicle is required to avoid a crash, since it is assumed that drivers will not place themselves in such a situation. Of approximately 36,000 vehicle pairs in the September data set, 230 pairs are rejected. To create a sufficiently large pool of potential crashes for the quasi-Monte Carlo approach, the database is cycled through one hundred times, representing over 3.5 million POV braking events. With the parameter sets described below, about four to six hundred potential crash pairs are identified, representing about one potential crash scenario for every 6000 vehicle pairs.

REAMACS, of course, could use other databases, if they were available. Use of a single database based on loop detector data carries with it consequences. The simulation results cannot reflect FCW performance for different roadway or traffic conditions. Since the loop detectors will not record any stopped vehicles, crash scenarios with stopped POVs can only be generated as a byproduct of POVs decelerating within the simulation to a stop. Consequently, the model yields a smaller proportion of crash scenarios with stopped POVs (about one in three or four simulated crashes) than that described by statistical studies of the rear-end crash problem (67%, as reported in [10]). An area of potential follow-on work is the revision of REAMACS to create more cases of stopped POVs. Another consequence of the use of vehicle pairs is that no multiple-vehicle crash scenarios are addressed in this work.

Given valid data from a vehicle pair, the simulation begins a braking deceleration by the POV. The braking level is drawn from a normal distribution of mean -0.17g and standard deviation of 0.10g, based on field measurements of over 4000 vehicles at 12 sites of discretionary braking [6]. In simulation, this distribution is sampled until a draw between -0.06g and -0.80g is made. In the simulation, the POV continues braking to a stop. (Section C.8.2 looks at the sensitivity of results to POV deceleration levels, as does [3]).

The SV driver's response to the lead car braking; is quantified by the perception reaction time and the braking intensity. Driver reaction time to lead car braking is modeled as a sample from a lognormal distribution with a headway-dependent mean and standard deviation. This model is based on work of Olson [11], which presented subject drivers with a surprise roadway obstacle and measured time until the brake was touched. The lognormal distribution provides a significant "tail" of long response times to model inattentive or distracted drivers. The dependence on headway is intended to model increased alertness for tailgating drivers; this effect is not well understood and is examined in only two studies [12][13]. The mean and standard deviation of the log-normal distribution are assumed to be linearly increasing with headway between 0.5 and 3.0 seconds. The log-mean ranges from $\ln(1.1) = .096$ to $\ln(1.5 \text{ sec}) = .405$ as headway varies from .5 sec to 3 seconds. The log-SD varies from 0.15 to 0.4 over the same headway range. For headways greater than 3 seconds, the distribution parameters do not change, and are directly from [11].

Braking intensity applied by the SV driver is modeled as 0.7g to represent a driver's attempt to avoid a crash by braking hard. A delay of 0.2 seconds is applied between the driver's brake application and a change in the SV deceleration; this represents the dynamics of the braking system. Given the simulated SV driver's response to the lead car braking, the simulation computes whether a rear-end collision occurs. If so, the vehicle pair and its associated randomly sampled POV deceleration level and following driver reaction time to the braking event becomes one member of the crash data set. The impact speed is stored for later comparison with the response of an FCW-aided driver.

Two assumptions are implied by the SV driver model just described. First, it is assumed that the pavement will support a 0.7g braking event – i.e., that for those cases where this level is required, dry pavement is implicitly assumed. Approximately eighty percent of police-reported rear-end collisions occur on dry pavement [14]. Second, the computer simulation assumes that braking is the only countermeasure taken by the driver – the possibility that steering might be used successfully to avoid a crash (either with or without a FCW present) is not addressed.

Once all vehicle pairs in the database have been processed in this fashion, the combinations of vehicle pairs define the potential crash scenarios and random number draws that led to crashes. These cases are used in a second simulation pass, this time with a FCW present. The second pass re-uses the values for the lead car braking level and the SV driver response time to the braking event. Models are added for range sensing and computation of the warning algorithm. Sensing of the range and range rate to the lead car is modeled as ideal, except for an upper bound on the range at which the sensor can help provide warnings, which is varied from 20 to 300 meters. A delay of 0.20 seconds is also associated with the availability of range and range rate data. The simulation assumes perfect identification of appropriate targets. The warning algorithms are described in Section C.5.

In the second pass through the potential crash scenarios, the SV driver may be motivated to brake either by his or her reaction to the lead car braking (as in the first pass), or by an alert from the warning algorithm. Response time to the alert is drawn from a normal distribution with mean and standard deviation of 1.10 and 0.305 seconds, respectively. This follows from [11]. The driver is assumed to brake based on whichever response time finishes first and the same 0.7g braking level is used. If the response to the alert occurs first, then the 0.2 sec braking system is applied again, and the crash may be mitigated or prevented due to the alert. The potential for reduction in harm is the percent decrease in the sum over all crash data sets of the squared impact speed, as described in Section C.3.

C.4.3 Outputs of the REAMACS Tool

To illustrate the outputs of the REAMACS tool, Figure 5 shows the output listing from a single REAMACS run using the closing speed warning algorithm and the cautionary crash alert parameter set. The upper section of the output of Figure 5 reports baseline tallies. These include: the number of vehicle pair scenarios investigated (100 iterations of 35,683 vehicle pairs, or over 3.5 million total pairs); the number of warnings that are triggered by vehicle pair state values as read directly from the database (1600, or 448 per million vehicle pairs); and the number of crashes that occur without a FCW to aid the driver (669, or 187.5 per million vehicle pairs). The second and third sections provide statistical counts of the number of crashes with and without a FCW; in this example, system ranges of zero (no FCW) to 300m are studied. ”Police Crashes” (or “PR” crashes, for “police-reportable”) are simulated crashes with a relative impact speed of 4.6m/sec or greater (about 10 mph), since this is roughly the speed at which significant vehicle damage can be expected. For instance, in the last column in the first large table, it is seen that a system with a 100m range reduces “Police” crashes by 51% in the simulation. The bottom table in Figure 5 includes two results of note. First, for each system range, the simulated crashes are sorted into bins reflecting the impact speeds, for example, for a system range of 0m (no FCW), there are 407 crashes with impact speeds of 10 mph or less. Second, the table presents the relative harm computed for each system range. The figure show, for example, that the normalized relative harm for a FCW with a 100m range is 30%, for a potential 70% reduction in relative harm.

The second table in Figure 5 shows that with a system range of zero (no FCW), there are 250 PR crashes, or 250/3.57million = 70.1 PR crashes per million REAMACS braking events. An earlier REAMACS paper, Farber and Paley [4], reported 65 PR crashes per million events (the number is slightly larger in this report due to an improved random distribution clipping routine, as described earlier). In [4], Farber and Paley estimate the actual frequency on U.S. roads as between 4 and 40 PR crashes, based on Farber’s estimate of one PR rear-end crash per 2.5 million foot-off-throttle events, and one full stop in every 10 or 100 such events. Thus REAMACS generates rear-end crashes at a higher rate than actual traffic by a factor of about 2 to 18, depending on assumptions. Recall, though, that REAMACS is used here primarily to *compare* different warning algorithms and to *approximate* the potential for reducing harm. It does not necessarily provide accurate predictions of absolute performance, such as absolute reductions in crashes.

C.4.4 Regarding Interpretation of Simulation Results

Modeling is by definition a simplified version of reality. Some issues that may be important in real-world reduction in harm are not treated in this work. A few of these are:

- Non-ideal values for deployment and use of FCWs by drivers are not treated.
- The analysis does not treat the possibility that some drivers will not always comply with FCW warnings with prompt braking. (False alarm rates may reduce the drivers reflexive use of brakes to a warning, reducing effectiveness even of timely warnings.)
- No risk compensation effects are treated in this work. (Risk compensation may have a variety of effects on actual benefits.)
- Sensing imperfections by the FCW target sensing system are assumed to include only range limitations and time delay. Errors in identifying and tracking in-path targets are not treated.

```
Reamacs4f - CRA - 0.0 Minimum Headway
08-18-1997    07:49:00

CAMP algorithm, cautionary level -0.3g, 2.5sec

File size = 35683 veh pairs
Number of iterations = 100
Total count = 3568300
Total warnings =  1600
Warnings/million vehicle pairs =    448
Total crashes = 669
Crashes/million vehicle pairs =  187.5
Warnings per crash = 2

Run time = 2006.602
```

System Range (m)	Total Crashes	Police Crashes		Mean Impact Speed (mph)	Percent Reduction in Crashes	
		Number	Percent		Total	Police
0	669	250	37.4	11.6	0.0	0.0
20	526	218	41.4	12.6	21.4	12.8
50	486	184	37.9	11.2	27.4	26.4
75	442	130	29.4	8.8	33.9	48.0
100	432	122	28.1	8.4	35.6	51.6
150	431	121	28.1	8.4	35.6	51.6
300	431	121	28.1	8.4	35.6	51.6

DeltaV (mph)	System Range (m)						
	000	20	50	75	100	150	300
0 to 10	407	299	293	302	300	300	300
10 to 20	153	120	104	98	96	96	96
20 to 30	54	52	54	36	31	31	31
40 to 50	18	18	6	1	1	0	0
50 to 60	8	8	0	0	0	0	0
60 to 70	0	0	0	0	0	0	0
70 to 80	0	0	0	0	0	0	0
80 to 90	0	0	0	0	0	0	0
Relative Harm	100 %	93%	63%	33%	30%	29%	29%
Potential for Reduction in Relative Harm	0%	7%	37%	66%	70%	71%	71%

Figure 5 Sample REAMACS Output. Closing Speed Algorithm, Cautionary Crash Alert

- Dry pavement is assumed for simulating hard braking to avoid collisions. (Eighty percent of crashes occur on dry pavement [14], but there has been no attempt here to model the reduced braking capability wet pavement can support – this can be expected to reduce the benefit by several percent.)
- The computation of metrics uses braking as the sole countermeasure, although evasive steering action can be more effective in some situations. Studies have shown that drivers are more likely to use braking alone than steering alone [15]. (The effect of this is unknown. On one hand, this assumption may exaggerate the effects of the warnings, as drivers who react late to a rear-end collision situation may avoid a crash by steering, whereas the analyses here assume only braking is available. On the other hand, a FCW may also alert a driver in time to use steering effectively.)
- Driver-interface design effects are not considered. Drivers are assumed to always understand and respond appropriately to alerts.
- Multiple-vehicle rear-end collisions are not studied. Whether the effectiveness of FCWs will be greater or less is not known.

C.5 Warning Algorithms Used in the Analysis

This section presents the two warning algorithms considered in this report, a "closing speed" algorithm, and a "POV deceleration" algorithm. These two algorithms are often used by researchers studying rear-end collision countermeasures. Other algorithms studied by other researchers include warning algorithms based on time-to-collision, algorithms using headway terms, and algorithms using assumptions regarding POV and subject vehicle decelerations that are different than those used in the POV deceleration algorithm described here. These other algorithms are not treated here, but remarks regarding a few of them are offered later in this section.

C.5.1 Warnings Based on Closing Speed

The closing speed warning algorithm in the subject vehicle (SV) issues a warning when the following distance to the lead vehicle, or the "principal other vehicle" (POV), falls below a threshold. The threshold depends on the closing speed, as well as on parameters of a model describing a model of the SV driver's reaction to the alert. Assume the SV driver reacts so that the SV begins a step acceleration of magnitude $a_{sv} < 0$ (negative for braking) at a time RT_W after the alert sounds. Let V_{sv} and V_{pov} denote the speeds of the SV and the POV, respectively. Consider a warning issued when two conditions are satisfied: (1) the SV is closing on the POV, $V_{sv} > V_{pov}$, and (2) the range R from the SV to the POV becomes equal to or less than a warning threshold, R_W:

Equation (1)

$$\text{Warn when } V_{sv} > V_{pov} \text{ and } R \le R_W = RT_W \cdot (V_{sv} - V_{pov}) + \frac{(V_{sv} - V_{pov})^2}{-2a_{sv}}$$

The first term in the expression for the threshold R_w is the distance the SV closes on the POV during the design value of the driver's perception-reaction time. The second term is the distance the SV closes on the POV before a deceleration by the SV of design value a_{sv} brings the closing speed to zero. Therefore if the SV and its driver behave exactly as the algorithm design model assumes – i.e., a time RT_w after the alert is issued, an acceleration $a_{sv} < 0$ is applied – then the range and range rate will go to zero at the same instant, and the SV will barely touch the POV. That is, the alert occurs at the last possible instant for the modeled SV and SV driver to avoid a collision. If the actual driver's response is more aggressive than the model assumes, no contact will occur. If the driver's response is less aggressive than the model assumes, an impact occurs, although the impact is likely to be less severe than if no collision warning was issued.

Three parameter sets are studied in this report. Two sets correspond to the "cautionary crash alert" and the "imminent crash alert" requirements. A third set is also studied in this document; this set is called the "intermediate" set, and uses driver reaction parameter values between the cautionary and imminent requirements:

(Equation 2)

$(RT_w, a_{sv}) =$	(2.5 sec, -0.3g)	"cautionary crash alert"
	(1.5 sec, -0.5g)	"imminent crash alert"
	(1.5 sec, -0.3g)	"intermediate"

A major drawback of the closing speed algorithm; is that any deceleration of the POV that occurs between the moment of alert and the time at which the closing speed is brought to zero, violates the assumptions made in deriving the algorithm – any POV deceleration during this period requires a more aggressive driver response than that described by the design parameter set (RT_w, a_{sv}). Therefore this algorithm requires a design tradeoff between performance in situations of decelerating POVs and situations with constant speed POVs (including the case of a stopped POV). The alert may feel "late" when the POV is decelerating, or an increase of in-path nuisance alerts may result in situations of non-decelerating POVs.

C.5.2 Warnings Using Information on POV Deceleration

The tradeoff that the closing speed algorithm requires between performance with decelerating and non-decelerating vehicles is eased if information regarding the POV's deceleration is available. This information may be gathered by estimation using ranging sensor measurements (e.g., differentiating range rate), through assumptions or inferences of POV deceleration, or received by cooperative means (e.g., from a transponder on the POV). Regardless of the technology, the use of POV deceleration can provide timely alerts with fewer in-path nuisance alerts.

Consider a warning algorithm that uses the same model as before to describe the SV driver's reaction to an alert, but now assumes that POV deceleration, $a_{pov} \le 0$, is known, and that the POV will continue to decelerate to a stop. Assume also that the SV acceleration between the moment of the alert and the beginning of the SV driver's deceleration response is zero. A conditional algorithm results, as shown in Equation 3.

Equation (3)

For $a_{pov} = 0$ and $V_{sv} > V_{pov}$:

$$R_w = \frac{(V_{sv} - V_{pov})^2}{-2a_{sv}} + RT_w(V_{sv} - V_{pov})$$

For $a_{pov} = 0$ and $V_{sv} \le V_{pov}$:

$$R_w = 0$$

For $a_{pov} < 0$:

If $V_{sv} > V_{pov} + a_{pov}RT_w$ and $-\frac{V_{sv}}{a_{sv}} < -\frac{V_{pov}}{a_{pov}} + RT_w$:

$$R_w = max\left(0, \frac{(V_{sv} - V_{pov} - a_{sv}RT_w)^2}{2(a_{pov} - a_{sv})} + \frac{1}{2}a_{sv}RT_w^2\right)$$

Else

$$R_w = \max\left(0, \frac{V_{sv}^2}{-2a_{sv}} - \frac{V_{pov}^2}{-2a_{pov}} + V_{sv}RT_w\right)$$

If the POV does indeed maintain constant braking deceleration until it stops, and the SV driver's braking response matches exactly the design model, then again the range and the range rate will both go to zero at the same instant – the SV will barely touch the POV. This can be seen in the equation above. If the first conditional statement applies, the algorithm is identical to the closing rate algorithm. The last two equations for the warning threshold R_w apply if the POV is decelerating; the two equations apply when, respectively, the potential collision would happen while both vehicles are moving, or when the POV has come to rest.

In practice, the potential benefits of using POV deceleration in a warning algorithm may not be fully achieved, due to implementation issues. For example, obtaining POV deceleration may involve differentiating noisy range and/or range-rate information as well as lowpass filtering to remove noise and provide a reliable signal. This adds significant lag, on the order of one to two seconds in some current radar- or laser radar systems. In addition, even if perfect instantaneous knowledge of POV braking deceleration is available, the warning algorithm still cannot predict whether the POV will continue to decelerate, or is simply engaging in a short braking event. The warning algorithm is based on assumptions of the future braking forces; these assumptions will influence the algorithm's performance over the variety of actual driving situations.

C.5.3 Remarks on Warning Algorithms and Parameters

Many warning algorithms studied here have been proposed by researchers. Many algorithms are similar to the two described above in that warnings are issued based on a model of the kinematics of the vehicle pair during and after the time of the alert. Various assumptions may be made regarding information available to the warning algorithm (e.g., acceleration measurements for one or both vehicles), the deceleration profiles before and after the SV driver's response to the alert, and the model of the SV driver's perception-reaction time. At least one algorithm – that based on time-to-collision [16] – is not based on a model of the driver response. Another algorithm *assumes* a POV deceleration value, without direct measurement or estimation. This algorithm [9] attempts to combine the advantages of using POV deceleration information with the simpler hardware and software requirements of the closing speed algorithm. Although there are many variations of warning algorithms, even if time and resources were available, an extensive comparison of these various algorithms may not be justified since there may not be enough data about actual braking behavior to construct a meaningful comparison between similar algorithms.

C.6 Results for Potential Reduction in Relative Harm

The previous sections described the database and models used to estimate the potential reduction in harm. This Section reports simulation results for the two warning algorithms and three sets of warning algorithm parameters presented in the previous section over sensor ranges from 20 to 300 meters. Sensor range is defined as the range limitation of the system, i.e., the range beyond which the system cannot provide warnings. Later in the report a method of estimating in-path nuisance alerts for these same algorithms and conditions is described and results presented (Sections C.7 and C.8.)

Table 1 summarizes the different results for estimating the potential reduction in relative harm for the closing speed algorithm. Each cell of the table represents a single run of REAMACS; the example described in Section C.4.3 appears on the bottom row, under the 100m column. Consider first the effect of sensor range on the potential to reduce relative harm. It is seen that for all three sets of algorithm parameters, there is small additional benefit for systems with a range greater than75m. With regard to the influence of the warning parameters, the earlier alerts provided by the cautionary parameter set yields a much higher potential than the other two sets. Clearly, the selection of the warning parameters has a strong influence on the potential reduction in harm.

Table 2 presents corresponding results of the reduction in the number of crashes from the same set of simulation runs. The first column shows that there are 70.1 police-reportable (PR) crashes per million REAMACS braking events when no FCW is present. For the 100m Alert Zone extent, the second column of Table 2 shows corresponding numbers with the FCW simulated. The third column shows that the effect of the FCW on the number of PR crashes depends strongly on the parameter set – the cautionary set provides a 51% reduction in the number of PR crashes, while the imminent set provides only a 5% reduction. Note that a 0.5% increase in non-PR crashes occurs with the imminent crash alert – this is not a cause for concern, since though many non-PR crashes are eliminated with the FCW, many crashes which were PR crashes become non-PR crashes with the introduction of the FCW. Note, too, that the values for reduction in relative harm reported in Table 1 are generally greater than the values for reduction in crashes reported in Table 2. The harm metric measures effects of eliminating crashes *and* mitigating crashes. The harm metric also reflects that it is more important to reduce the impact speed in a severe crash than to eliminate a minor crash.

Table 1 Potential Reduction in Relative Harm for Closing Speed Warning Algorithm

	Potential for Reduction in Relative Harm (Versus Cases with Crash Potential)					
	Maximum Warning Range					
Warning Algorithm Parameter Values:	**20m**	**50m**	**75m**	**100m**	**150m**	**300m**
-0.5g, 1.5sec Imminent	2%	18%	20%	20%	20%	20%
-0.3g, 1.5sec Intermediate	3%	27%	42%	44%	45%	45%
-0.3g, 2.5sec Cautionary	7%	37%	67%	70% (see Fig 4)	71%	71%

Note: Each run consists of 100 iterations through the entire database.

Now consider the warning algorithm that uses POV deceleration information, Equation 3 in Section C.5. Table 3 and Table 4 present simulation results for the potential for reduction in relative harm and the possible reduction in the number of crashes. In Table 3, notice that the benefit of the FCW increases significantly up to about ranges of 75m or 100m. For the cautionary set, there is a 90% potential for reduction in relative harm with a 100m system, and Table 4 shows that 87% of PR crashes are avoided with the FCW in these experiments. In fact, for all algorithms considered a system range of 75m gives at least 94% of the total potential possible with an unlimited (300m) range. One caveat, however since REAMACS and the database that is used combine to under-represent the situation in which a POV is stopped at collision time. The 75m value described here, as being the "knee" of the curve may be lower than the range found if POV -stopped cases were properly represented.

It should also be noted that the difference in the reduction in relative harm numbers is smaller between the parameter sets than it was for the closing rate algorithm. This is because the use of any of the three-parameter sets provides a quite effective FCW for these simulated situations. As stated in Section C.5; after the initial 1.2-second time delay in the simulated algorithm, the FCW "knows" exactly the kinematics of the situation, and since the "drivers" comply perfectly, crashes can only happen when either the reaction times drawn exceed the design times of 1.5 or 2.5 seconds, or when the time delay of the FCW impacts its effectiveness (which is not often, in these simulations).

Table 2 Reduction in Number of Crashes: Closing Speed Warning Algorithm. 100m Alert Zone Extent

	No FCW	With FCW	Percent Change with FCW
PR crashes (impact speed > 4.6m/sec), per Million REAMACS braking events			
Imminent 1.5sec RT, -0.5g	70.1	66.4	-5.2%
Intermediate 1.5sec RT, -0.3g	"	58.0	-17%
Cautionary 2.5sec RT -0.3g	"	34.2	-51%
Non - PR crashes (impact speed < 4.6m/sec):			
Imminent 1.5sec RT, -0.5g	117	118	+0.5%
Intermediate 1.5sec RT, -0.3g	"	116	-1.2%
Cautionary 2.5sec RT -0.3g	"	86.9	-26%
All Crashes			
Imminent 1.5sec RT, -0.5g	187	184	-1.6%
Intermediate 1.5sec RT, -0.3g	"	174	-7.2%
Cautionary 2.5sec RT -0.3g	"	121	-35%

Table 3 Potential Reduction in Relative Harm for Warning Using POV Deceleration Estimates (Delay in Getting POV Deceleration = 1.2 sec.)

	Potential for Reduction in Relative Harm (Versus Cases with Crash Potential) Max Warning Range					
Warning Algorithm Parameter Values:	20m	50m	75m	100m	150m	300m
-0.5g, 1.5sec Imminent	3%	36%	81%	85%	87%	87%
-0.3g, 1.5sec Intermediate	3%	37%	81%	86%	87%	87%
-0.3g, 2.5sec Cautionary	7%	41%	85%	90%	91%	91%

Table 4 Potential Reduction in Crashes: Warning Using POV Deceleration Estimates – 100m Alert Zone Extent

	No FCW	With FCW	Percent Change with FCW
PR Crashes (Impact Speed > 4.6m/Sec), per Million REAMACS Braking Events			
Imminent 1.5sec RT, -0.5g	70.1	14.3	-80%
Intermediate 1.5sec RT, -0.3g	"	13.5	-81%
Cautionary 2.5sec RT -0.3g	"	9.25	-87%
Non- PR Crashes (Impact Speed < 4.6m/sec):			
Imminent 1.5sec RT, -0.5g	117	106	-9.3%
Intermediate 1.5sec RT, -0.3g	"	103	-13%
Cautionary 2.5sec RT -0.3g	"	74.8	-36%
All Crashes			
Imminent 1.5sec RT, -0.5g	187	121	-36%
Intermediate 1.5sec RT, -0.3g	"	116	-38%
Cautionary 2.5sec RT -0.3g	"	84.1	-55%

Comparing Table 3 to Table 1, it is seen that the potential for reducing relative harm is significantly higher for the warning algorithm that uses POV deceleration than for the closing speed algorithm. This is because the alert is an “earlier” alert for the same parameter set. That is, for a given scenario of POV braking, an alert that uses POV deceleration will almost always occur before an alert based only on closing rate. In fact in a 100m range system, the potential reduction in harm is larger for the POV deceleration algorithm using the “imminent” parameters (85%) than the closing speed algorithm using the cautionary parameters (70%). It is clear that the additional information of POV deceleration may be very useful for a warning algorithm. However, it must be noted that this algorithm assumes that the POV will brake all the way to a stop and thus may be more likely to produce nuisance alarms under a given set of conditions than the closing speed algorithm.

C.7 Estimating In-Path Nuisance Alerts

A new simulation tool was created to compute in-path nuisance alerts, using the same database and scenarios used in REAMACS. This has been named In-Path Nuisance Alert Code (IPNAC). This section describes the modeling of in-path nuisance alerts, and presents results for the same conditions as those addressed for REAMACS in the previous section.

C.7.1 Definition

For this early study, in-path nuisance alerts are defined as follows. An in-path nuisance alert is any alert which occurs in a situation in which the driver – reacting either to the POV braking event itself or to the alert – can brake with his or her “normal” braking intensity and avoid a collision. We assume for now that application of the brakes suppresses a rear-end collision alert, so that if the driver touches the brake pedal in response to his or her perception of the POV braking before the alert sounds, then the alert will not sound during that braking event.

This definition of in-path nuisance alert allows two ways for a nuisance alert to occur during a braking-to-POV -deceleration event. In the first, the driver perceives the need to brake, but before he or she touches the brake pedal, the alert sounds; furthermore, a collision is avoided using only "normal" braking. In the second case, the alert sounds before the driver either notices the situation or before he or she has decided to brake, but nevertheless, the collision is avoided using only “normal” braking. The next subsection clarifies the definition by posing a comprehensive framework into which all alerts that occur with the REAMACS approach can be categorized.

In-path nuisance alerts are very likely with FCWs because warning systems cannot distinguish between drivers who are aware of the traffic situation and drivers who are not aware, due to inattentiveness, distraction, or other reasons. The alert must occur soon enough, to allow for the unaware driver’s perception-reaction time to an alert. Thus the FCW will occasionally annoy those drivers who are aware of the situation and do not consider themselves in danger. Because vehicles are capable of much higher levels of braking than the discretionary levels of braking normally used by alert drivers, it is possible to delay a warning well beyond the point at which most alert drivers would normally begin to brake. Because of the need to allow for a continuously decelerating POV, the algorithm may give a warning at a time that will allow a crash to be avoided with moderate braking. Such alarms are likely to be regarded as nuisances by alert drivers. A practical algorithm design will seek- to minimize these instances by delaying alerts as long as possible, while still allowing enough time for an inattentive driver to respond safely. It is believed unlikely that the in-path nuisances will be completely eliminated, and those that do occur may affect the driver acceptance, system usage, and compliance with non-nuisance alerts. This report does not include an attempt to estimate this effect. The analysis here is restricted to the estimation of in-path nuisance alerts that may accompany the algorithms. We anticipate that further work will be necessary to estimate the effects of nuisance alarms on realizable harm reduction.

C.7.2 Partitioning Warning Alerts

In the REAMACS scenario, the POV of a vehicle pair begins braking at a randomly chosen discretionary braking level, and continues to brake to a stop. The SV is assumed to be in the same lane as the POV, so that it too must brake to a stop if a rear-end crash is to be avoided. Recall that only braking is considered as a crash avoidance response, and steering maneuvers are not treated. Here a partitioning of the set of all alerts that may occur in braking-to-POV-deceleration events is described. Alerts are partitioned into three categories: "beneficial" alerts, in-path nuisance alerts, and alerts which are neither. Alerts are partitioned based on three factors:

1. When the alert occurs, with respect to the onset of lead car braking.

2. What causes the following car driver to begin braking (the onset of lead car braking or the alert).

3. The level of braking needed to avoid a collision.

First, consider only factors (1) and (2). Three cases are used to describe when an alert occurs during a braking-to-POV event, and what causes the driver to brake during that event. Let Case 1 describe REAMACS events in which the driver brakes due to his or her perception of POV braking, and braking is soon enough so that the alert is suppressed. (It is assumed that brake pedal application suppresses any un-issued alert.) The timeline at the top of Figure 6 describes this case. In the figure, the driver's reaction time to lead car braking is completed before the alert sounds.

Consider a second situation, Case 2, in which the alert sounds just before the brake pedal is applied, but braking is due to the driver's own detection of lead car braking. This is illustrated in the center box of Figure 6. Finally consider Case 3, in which the alert sounds before the driver has perceived the need to brake and therefore provides the stimulus for brake application. This is shown in the bottom box of Figure 6.

The third factor listed above is the amount of braking intensity necessary to avoid an impact. Two generic levels of braking are suggested for purposes of partitioning the alerts. Let braking levels be described as "Normal (or less)" and "Hard" braking. The corresponding deceleration rates will be specified later in the report. With the three cases of alert timing and braking stimuli described in the previous paragraphs and the two levels of braking suggested here, a partitioning of alerts into six subsets is now proposed and illustrated in Table 5. The three cases of alert timing and braking stimulation define the three columns in Table 5; the two braking levels define two rows. The six cells are now discussed.

The first column of Table 5 denotes braking events in which the driver brakes before the alert sounds; for now, the braking level is irrelevant, since the immediate objective is to estimate in-path nuisance alerts. The second column of Table 5 corresponds to Case 2 above – i.e., situations in which the driver perceives the need to brake, but before the brake pedal can be applied, the alert sounds. In this case, it is suggested that if the driver can avoid impact using only normal braking, he or she will consider the alert a nuisance. This is shown in Table 5. If, however, "Hard" braking is required, drivers may not consider the alert a nuisance – perhaps some may welcome the alert as an indication that the FCW was ready to assist them. Finally, for Case 3, which denotes situations in which the alert causes the driver to brake, it seems obvious that when "Hard" braking is required, drivers will generally perceive the alert as "helpful," since a crash may be averted or mitigated by the alert. If "Normal" braking is sufficient to avoid a crash, the driver is assumed to consider the alert a nuisance, and this is indicated in Table 5.

Table 5 Partitioning Alerts into Six Cells

Braking Level Required to Avoid Crash	**Timing of FCW Alert and Cause of Subject Vehicle Braking**		
	Case 1	Case 2	Case 3
	No FCW Alert. Braking is due to driver reaction to POV braking. Braking suppresses FCW alert.	FCW Alert occurs, but Braking is due to driver reaction to POV braking. Braking occurs after alert, but before RT to alert.	FCW Alert occurs. Braking is due to driver reaction to alert.
Normal (or less)	No In-Path Nuisance Alert	In-Path Nuisance alert	In-Path Nuisance alert
Hard	No In-Path Nuisance Alert	Not an in-path Nuisance. (Event validates alarm for driver)	Not an In-Path Nuisance. (Alert mitigates/prevents crash)

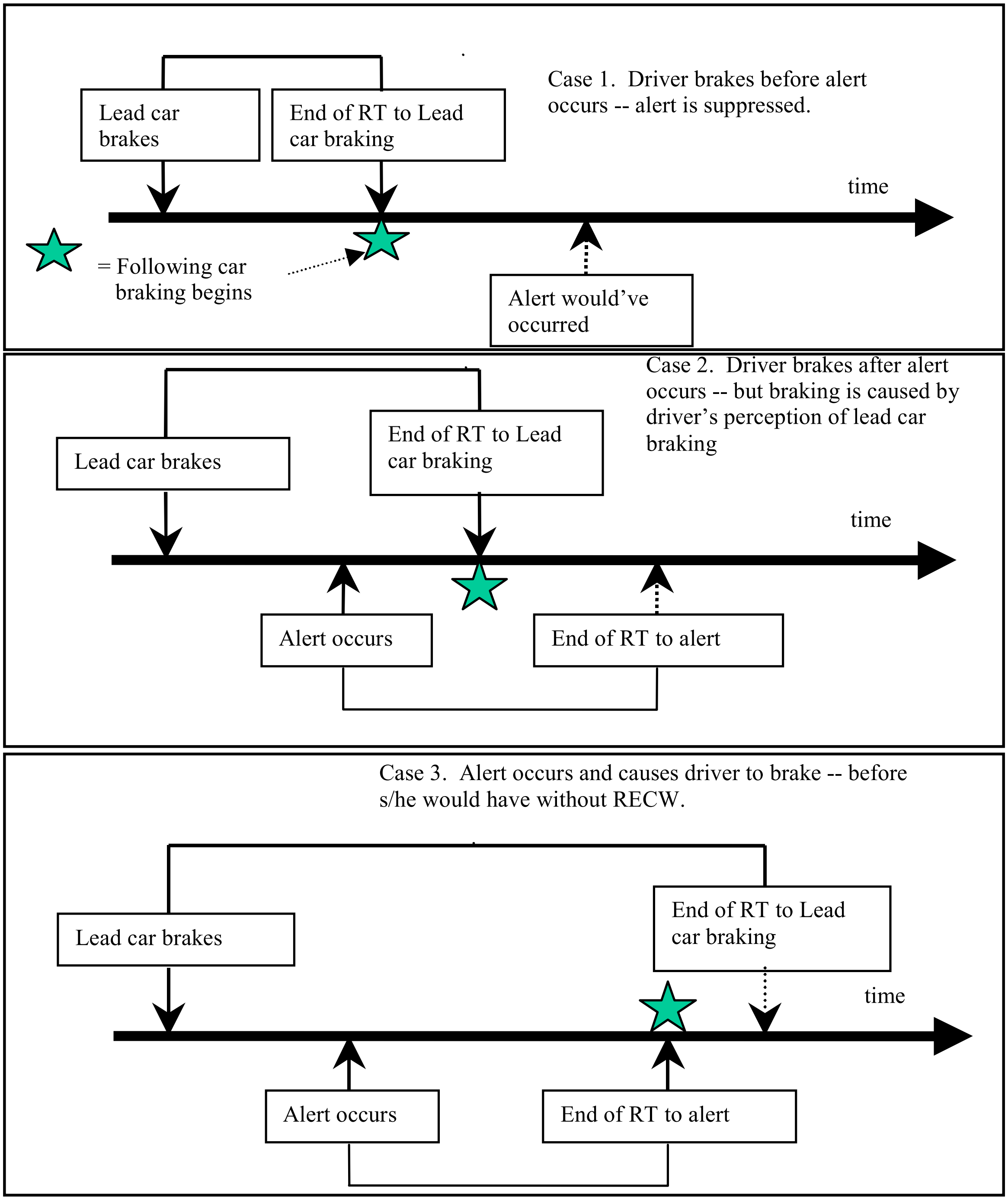

Figure 6 Three Cases of When Alerts May Occur and the Corresponding Stimuli for Braking

C.7.3 Simulation Logic

Here we describe a method to estimate the in-path nuisance alert rate. To estimate the frequency of in-path nuisance alerts, the simulation tool IPNAC uses the FHWA database in the same manner, as does REAMACS. In IPNAC, for each vehicle pair, the following car driver brakes in response to either the lead car braking (using the same driver reaction time to braking model as before) or the collision alert (using the same driver reaction time to an alert, as before). The stimulus for braking is the event for which the driver's reaction time is completed first. No matter the stimulus, a "Normal" braking intensity is selected for the following car deceleration. If an alert occurs and the collision is avoided, then according to the previous definition of an in-path nuisance alert, that simulated case represents an occurrence of an in-path nuisance alert.

The model of the "normal" following car braking is a random sample drawn from a normal random variable distribution with a mean of -0.25g and a standard deviation of 0.025g. These values are chosen based on a very small sample of Task 4, Study 1 data. This is the average and standard deviation of the first six subjects' required decelerations to avoid a collision when making last-moment braking decisions at "comfortable" braking levels. Values outside the domain [-0.12g, -0.40g] are re-drawn; values outside this domain are assumed to be beyond normal, comfortable braking. Later in this report, the sensitivity of computed nuisance rates to these model parameters is explored. Once the SV begins to brake, the simulation is allowed to play out until either a collision occurs or does not occur. The results of each simulated braking event is then tabulated in a table like Table 5 described earlier.

To describe how simulation is used to evaluate in-path nuisance alerts, consider a single simulation study. The closing speed warning algorithm (Equation 1) is used with the cautionary settings (Equation 2), and an Alert Zone extent of 100m. In-path nuisance alerts are tallied for two to twenty cycles through the database, representing between 70,000 and 700,000 events of braking to a POV. The number of passes through the database is found by trial and error for each algorithm/parameter/range case, by running three Monte Carlos, and using each run for the number of cycles through the database required, so that the variation among the three runs is about five percent or less.

The averaged results are tabulated in Table 6 using the form of Table 5. The first column of the table shows that about 98% of the braking events for this example do not include a triggering of the alert – which is consistent with the fact that drivers almost always avoid rear-end collisions. The second column indicates that in 1.8% of the simulated cases the alert occurs but braking is due to the driver's own perception of the situation. Of these, 1,804 alerts per million events occur in situations where "normal" braking is sufficient to avoid an impact. These are in-path nuisances, as discussed in the previous subsection. The remaining 16,253 events in the second column represent cases in which "Normal" braking is not sufficient to avoid a collision. These cases then require at least "Hard" braking, so that these cases represent drivers braking harder than normal, based on their own perception of lead car braking, but with the alert sounding shortly before they can touch the brake pedal. Our assumption is that these would not be regarded as nuisances, but would be perceived as justifiable alerts.

Table 6 Example of Partitioning Alerts. Closing Speed Warning Algorithm, Cautionary Settings. Perfect Sensing with Alert Zone Limited to 100m

Braking Level Required to Avoid Crash	Timing of FCW Alert, and Cause of Subject Vehicle Braking		
	No FCW Alert. Braking is due to driver reaction to POV braking. Braking suppresses FCW alert.	FCW Alert occurs, but Braking is due to driver reaction to POV braking. Braking occurs after alert, but before RT to alert.	FCW Alert occurs. Braking is due to driver reaction to alert.
Normal (or less) (-0.25g mean)	819,993 alerts per 10^6 braking events	1,804 alerts per 10^6 braking events	6 alerts per 10^6 braking events
Hard	161,767 alerts per 10^6 braking events	16,253 alerts per 10^6 braking events	176 alerts per 10^6 braking events

The third column of Table 6 describes events in which the alert triggers the driver's braking; these total 182 per million simulations. Of these, there are six in-path nuisance alerts and there are 176 cases in which the alert causes the driver to brake in a situation in which higher-than-normal braking intensity is required to avoid an impact. These latter cases may be perceived by the driver as beneficial alerts, i.e., not in-path nuisance alerts.

For this case, Table 7 summarizes simulation results for potential for reduction in relative harm and in-path nuisance alerts. The first four rows were reported earlier: 51% reduction in PR crashes (from 70 to 36 per million REAMACS events), and 70% potential for reduction in relative harm. There are also 1,810 in-path nuisance alerts per million REAMACS events, 182 instances of alerts stimulating the braking, and 18,239 total alerts. *Thus, about 90% of all alerts for this example are neither nuisances nor beneficial alerts.* Instead, these alerts occur while the driver is in the process of responding to their own perception of the need to brake. Table 7 shows that there are 26 nuisance alerts per PR crash without the FCW. When all alerts are considered, there are 261 alerts per PR crash. These ratios provide a rough idea of how often in-path nuisances occur.

Table 8 shows corresponding results for a warning algorithm that uses POV deceleration information (Equation 3) with the cautionary parameter set (Equation 2). About 63,000 in-path nuisance alerts occur, with 5,161 alerts that stimulate braking, and there total of 125,000 total alerts. There are 901 in-path nuisance alerts per PR crash, and 1781 total alerts per PR crash. This alert is an "earlier" alert, hence a higher number of total alerts and in-path nuisance alerts. The ratio of nuisance alerts to alerts is lower, however, possibly because the algorithm can identify the cases in which the POV is decelerating hard, which are often dangerous cases.

C.7.4 Basic Simulation Results for In-Path Nuisance Alerts

Simulation results for in-path nuisance alerts are now presented for the same set of warning algorithms, algorithm parameters, and sensor ranges as reported earlier for potential reduction in relative harm. Table 9 shows in-path nuisance alerts per million REAMACS braking events for the closing speed algorithm (Equation 1), over the three parameter sets already defined (Equation 2), and for sensor ranges from 20 to 300m. These cases are the same as those studied for potential reduction in relative harm, Table 1 and Table 2. The example described in the previous section appears in the shaded cell of Table 9. Table 10 show results for the warnings issued using POV deceleration information (Equation 3); these cases are the same as those studied in Table 3 and Table 4. The example described in the previous section appears in the shaded cell of Table 10.

For Table 9, which shows results for the closing speed algorithm, two results are worth noting. First, in-path nuisance alerts rates are independent of sensor range for the cases studied using the closing speed algorithm. Second, in-path nuisance alerts rates are strongly dependent on the parameter set. As the alert becomes an "earlier" alert, more in-path nuisances occur. For instance, for an Alert Zone extending 100m, Table 9 shows 79.3 and 1,810 in-path nuisance alerts per Million REAMACS braking events for the imminent and cautionary settings, respectively. Since there are 70.1 PR crashes per Million REAMACS braking events, the ratio of these nuisances to PR crashes varies from about 1 to 26.

Table 10 shows the results for the warning algorithm with POV deceleration information included. Three remarks are in order. First, nuisances now increase with an increase of the Alert Zone's maximum range for the intermediate and cautionary parameter sets. Second, there is again a strong increase in the nuisance rate as the algorithm parameter set results in earlier and earlier alerts. Third, the number of nuisances becomes very large for these earlier alerts – for the cautionary parameter setting, with a 100m extent, 63,100 in-path nuisances occur per million experiments, or 901 in-path nuisance alerts per PR crash. This is 35 times the in-path nuisance rate seen with the closing speed algorithm. On the other hand, the imminent parameter set with the lead vehicle deceleration algorithm produces fewer nuisance alarms and a larger reduction in relative harm than the closing speed algorithm with the cautionary parameter set (see Table 1 and Table 2). This result is discussed further in the next section.

Table 7 Summary: Potential Reduction in Relative Harm and Accompanying Alert Results. Closing Speed Warning Algorithm with Cautionary Setting. Alert Zone Extent 100m

Percent reduction in PR crashes	51 percent
Reduction in Relative harm	70 percent
PR crashes without FCW	70 per Million REAMACS events
Reduction in PR crashes	36 per Million REAMACS events

In-path Nuisance Alerts introduced	1,810 per Million REAMACS events
Alerts stimulating braking at any level	182 per Million REAMACS events
Total number of Alerts	18,239 per Million REAMACS events

In-path Nuisance Alerts per PR crash	26
Total number of Alerts per PR crash	261

Table 8 Summary: Potential Reduction in Relative Harm and Accompanying Alert Results. Warning Algorithm with POV Deceleration Information, with Cautionary Setting. Alert Zone Extent 100m

Percent reduction in PR crashes	87 percent
Reduction in Relative harm	90 percent
PR crashes without FCW	70 per million REAMACS events
Reduction in PR crashes	61 per million REAMACS events

In-path Nuisance Alerts introduced	63,056 per million REAMACS events
Alerts stimulating braking at any level	5,161 per million REAMACS events
Total number of Alerts	124,655 per million REAMACS events

In-path Nuisance Alerts per PR crash	901
Total number of Alerts per PR crash	1781

Table 9 Closing Speed Algorithm: In-Path Nuisance Alerts per Million Simulated Braking Events (Mean of individual Monte Carlo Trials)

	In-Path Nuisance Alerts per Million Simulated Braking Events					
	Maximum Warning Range					
Warning algorithm parameter values:	20m	50m	75m	100m	150m	300m
-0.5g, 1.5sec Imminent	88.3	89.6	89.2	79.3	82.2	75.4
-0.3g, 1.5sec Intermediate	201	200	198	187	181	195
-0.3g, 2.5sec Cautionary	1,810	1,910	1,950	1,810	1,830	1,780

Table 10 Warnings Using POV Deceleration: In-Path Nuisance Alerts per Million Simulated Braking Events (Mean of Individual Monte Carlo Trials)

	In-Path Nuisance Alerts per Million Simulated Braking Events					
	Maximum Warning Range					
Warning algorithm parameter values:	20m	50m	75m	100m	150m	300m
-0.5g, 1.5sec Imminent	833	897	948	943	1,020	922
-0.3g, 1.5sec Intermediate	3,650	14,700	19,600	21,700	22,900	22,900
-0.3g, 2.5sec Cautionary	8,250	38,000	54,400	63,100	67,800	67,900

C.7.5 Balancing Potential Reduction in Relative Harm and In-Path Nuisance Alerts

Examination of the two tables just discussed indicates the possibility of finding an algorithm to produce a high potential reduction in relative harm and also keep the in-path nuisance alert rate relatively low. A simulation study was conducted to compute relative harm reduction and nuisance rates using POV deceleration and a variety of parameter sets that describe warning algorithm design models of "fast and firm" driver responses. These results appear in Tables 11 and 12. Consider an algorithm using a model for the driver's response to the alert as including a 1.25 second perception-reaction time and a braking intensity of –0.6g. The tables show a 79% potential for reduction in relative harm and 161 in-path nuisances per million REAMACS braking events, demonstrating that such a search for a more "optimal" algorithm may be useful. The point is not that this algorithm is considered "best," but rather to clarify that POV deceleration information allows more flexibility in tuning the algorithm, and that the apparently-higher nuisance alert rates in Section C.7.4 cannot be considered a reason to not use POV deceleration.

Table 11 Potential for Reduction in Relative Harm for Various Warning Algorithm Parameter Sets. Warnings Issued Using POV Deceleration Information. 100m Alert Zone Range Assumed.

asv, Parameter for Warning Algorithm	**RTw, Parameter For Warning Algorithm** (Blank cells indicate computations were not made for that case)			
	1.0 sec	1.25 sec	1.5 sec	2.5 sec
-0.3g			86%	90%
-0.5g	75%		85%	
-0.6g		79%		
-0.7g	41%		79%	

Table 12 In-Path Nuisance Alerts per Million REAMACS Braking Events, for Various Warning Algorithm Parameter Sets. Warnings Issued Using POV Deceleration Information. 100m Alert Zone Range Assumed.

asv, Parameter For Warning Algorithm	**RTw, Parameter for Warning Algorithm** (Blank cells indicate computations were not made for that case.)			
	1.0 sec	1.25 sec	1.5 sec	2.5 sec
-0.3g			21,700	63,100
-0.5g	61		943	
-0.6g		161		
-0.7g	12		301	

C.7.6 Metrics to Describe Frequency of In-Path Nuisance Alerts

So far the in-path nuisance alert results have been used to make comparisons between sensor ranges and alert algorithms, and thus the use of the unit "alerts per Million REAMACS events" has been sufficient. To express the simulation results as the frequency that such alerts occur per unit driving time, two simple approaches are used. First, the REAMACS database and braking scenarios are "calibrated" to real-world crash data to map "Million REAMACS events" to miles traveled.

Exposure to Police-Reported Rear-End Crashes

Reference [10] analyzes crash involvements using data primarily from the 1989-93 GES. For rear-end crashes, Table 4 and Table 5 in [10] state that the rate of vehicle involvement (as a striking vehicle (SV)) in actual police-reported rear-end crashes, per 100 million vehicle miles traveled (VMT) is 44.46 and 21.92 when the POV is stopped and moving, respectively. **This yields a total expected vehicle involvement in real-world police reported rear-end collisions (as the SV) of 66.38 per 100 Million VMT, or once per 1.51 Million VMT.**

The same tables indicate that expected involvement of a driver as the SV driver in a police-reported rear-end crash, over a driver's career (assumed to be 58 years), is 0.7308 and 0.3603 for POV stopped and POV moving, respectively. Section C.1 shows that these numbers are mislabeled, and they are actually the involvement of drivers of any vehicle involved in police-reported crashes. When only involvement as an SV is considered, the rate of vehicle (or driver) involvement per 58-year long driving career [10] are 0.3321 and 0.1637 for POV stopped and moving, respectively, for a total involvement as SV driver of 0.4958 police-reported rear-end crashes per driving career. Thus, under the assumptions of [10], the expected involvement of a driver, as the driver of the striking vehicle in a police-reported rear-end crash, is once per 117 years.

Correction to Wang et al, 1996: Rear-End Collision Involvement

This section presents a correction to two numbers in Wang et al [10] which describe expected driver involvement in the striking vehicle (SV) in a police-reportable (PR) rear-end collision. These numbers are used in Section C.7.6, "Estimated Exposure to In-Path Nuisance Alerts," to approximate, for the average driver, the time and mileage driven between in-path nuisance alerts. The present authors have discovered no other necessary corrections to [10].

Table 4 and Table 5 in [10] present statistics on two types of rear-end collision, respectively: rear-end, lead vehicle stopped (RE-LVS) crashes and rear-end, lead vehicle moving (RE-LVM) crashes. Among the statistics within each of the two tables is "Expected Involvement as SV in PR crashes – Per Driver over Driver Career". This is given for all vehicles combined; no breakdown between vehicle types is provided. For the RE-LVS and RE-LVM cases, respectively, reference [10] states the exposures as 0.7308 and 0.3603, which we will show is incorrect. The correct numbers are, respectively, are 0.3321 and 0.1637.

The miscalculation in [10] appears to be that exposures are computed for driver involvement in *any* vehicle involved in a PR rear-end, and not just in the SV. The reference states the formula used (p. 7, [10]):

$$\text{Expected number} = \frac{\text{Average annual number of involvements X Average driving career (years)}}{\text{Average number of registered drivers}}$$

The average driving career is estimated in [10] as 58 years; the average number (over the five years of statistics) of registered drivers used is not specifically stated, but can be backed out of other exposure rates as 170.1 Million. The average annual number of involvements of *all* vehicles is in RE-LVS crashes is 2.144 Million. The average annual number of involvements as the SV is 0.974 Million. Using the formula above gives the involvements per driver career as 0.7308 and 0.3603, respectively. The involvements for RE-LVM can be computed similarly.

As a check, consider that there were 1.454 million police-reported rear-end crashes annually [10]. Given that there are 170.1 million registered drivers in the U.S. (figure derived from [10]), then the expected number of drivers involved as the SV in a police-reported rear-end crash in a year is 1.454 M / 170.1 M = 0.00854 (which is 1/117).

Estimated Exposure to In-Path Nuisance Alerts

To estimate how often a driver might experience in-path nuisance alerts with a FCW, a scaling of results from simulation to "real world" is now performed. Recall that with no countermeasure in place, REAMACS produced 70.1 "police-reportable" crashes per Million REAMACS events, as reported in Table 2. Let this crash rate be denoted Cr. For the warning algorithm design selected in Section 0 (POV deceleration information available, and alerts based on a driver response model of 1.25 sec RT and –0.6g braking), 161 in-path nuisance alerts per Million REAMACS events were computed. Let this rate be denoted Nr, Nr = 161 IPNAs/10^6 REAMACS events. We use these two results, along with results from the previous subsection, to estimate the expected exposure of drivers to in-path nuisance alerts.

Let C denote a driver's expected annual involvement as the driver of the SV in a PR rear-end crashes, computed above, C = 1/117 PR crash/driving year. Let N be the estimated number of in-path nuisance alerts experienced annually by a driver. Then N = Nr (C/Cr), or

$$\mathrm{N} = \frac{161\ \text{nuisances}}{\text{M REAMACS events}}\, X\, \frac{1\ \text{PR crash} / 117\ \text{years}}{70.1\ \text{PR crashes/M REAMACS events}},$$

$$\mathrm{N} = 1\ \text{in - path nuisance alert per 50.9 years}\ .$$

Similarly, we can compute one in-path nuisance alert per 657,000 vehicle miles traveled. Table 13 shows results computed for two other cases as well – the two warning algorithms with the cautionary parameter setting. These numbers all indicate relatively rare in-path nuisance alerts.

These numbers are rough approximations. These computations assume that REAMACS produces two types of braking-to-POV events in the same proportions as they occur in U.S. traffic; these events are (1) police-reportable crashes (with no FCW in use), and (2) braking events which result in in-path nuisance alerts. This is illustrated in Figure 7. The frequency with which PR crashes occur depends primarily on the following variables: range, POV speed, SV speed, POV braking profile, and following driver reaction time to POV braking. The frequency of in-path nuisance alerts depends on the same variables, plus the warning algorithm and the driver's reaction time to the warning. If we assume that the REAMACS traffic database represents actual speed and headway behavior of drivers, then the assumption that events (1) and (2) occur in proper proportion. The simulation reduces the assumption that the reaction time distributions in the simulation are correct, and the POV braking profile is correct.

C.7.7 Previous REAMACS-Based Metrics for In-path Nuisance Alerts

Previous REAMACS reports used a different metric to estimate in-path nuisance alert rates [4]. This earlier approach is now described and the results compared to those presented above. The earlier method computes how often the initial conditions of the vehicle pair at time (directly from the database) causes a crash alert. For the cautionary setting of the closing speed algorithm, Figure 5 showed that 448 warnings were issued at time *To,* per million vehicle pairs, based on the vehicle pair speeds and gaps reported directly from the FHWA database. The reason for using this metric as an indication of in-path nuisance alerts is based on an assumption that in almost all cases, the following driver of the vehicle pair chose to be at that headway, and that furthermore almost all of them were not alarmed. Thus, the argument went, the 448 warnings per million vehicle pairs were almost all unnecessary and would be considered nuisances. Since Figure 5 shows 187.5 crashes per million vehicle pairs, the estimate of in-path nuisance alerts would then be 448 – 187.5 = 260.5 "nuisance alerts" per million vehicle pairs. This number compares with 1,810 in-path nuisance alerts, per million REAMACS braking events (Table 9) computed with the approach of this report. This larger number is more accurate, since now alerts at times other than the initial conditions are considered. Also note that the previous method of counting nuisance alerts did not address the possibility that some alerts that occur at initial conditions may be in truly alarming situations. The current analysis identifies these cases.

Table 13 Approximate Time- and Miles-Between In-Path Nuisance Alerts

(See assumptions in Section C.7.6)

Warning Algorithm	Parameter Set for Warning	Expected Time Between In-Path Nuisance Alerts	Expected Vehicle Miles Between In-Path Nuisance Alerts
Using POV deceleration	Special 1.25sec RT -0.6g decel	50.9 years	657,000 mi
Using POV deceleration	Cautionary 2.5sec RT -0.3g decel	0.13 years	1,700 mi
Closing speed algorithm	Cautionary 2.5sec RT -0.3g decel	4.53 years	58,500 mi

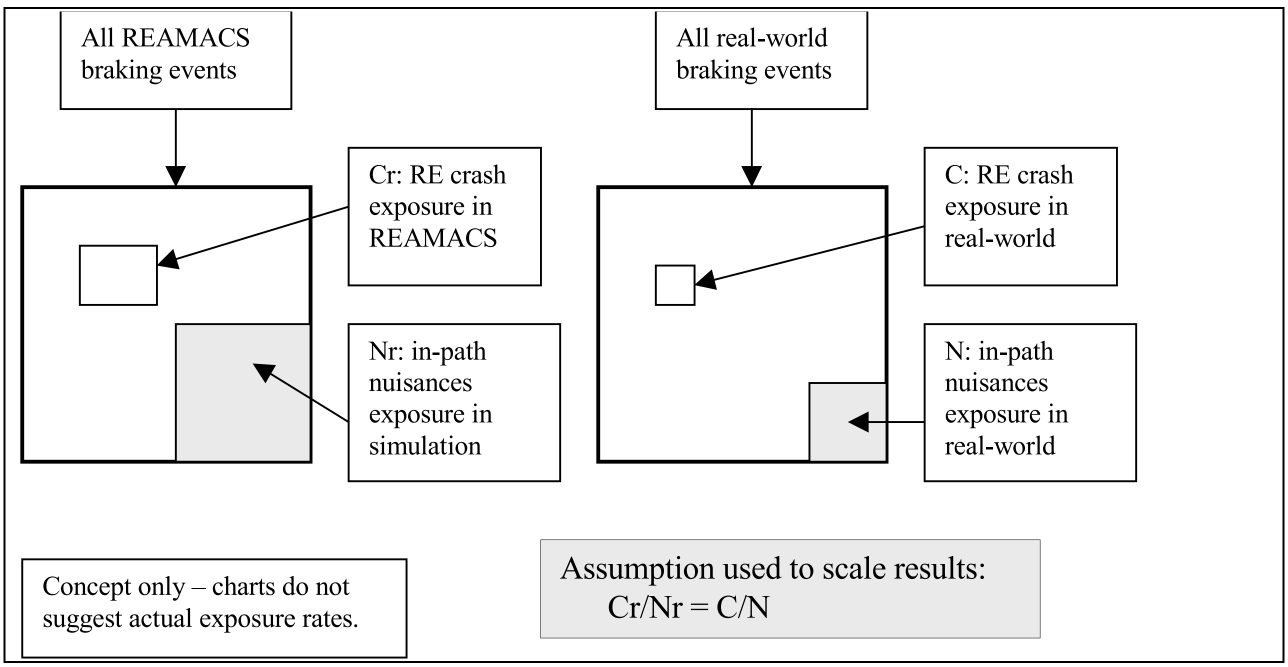

Figure 7 Assumption that the Ratio of Driver Exposures to PR Rear-End Crashes and in-Path Nuisances is the Same in Simulation and Actual U.S. Highway Experience

C.7.8 In-Path Nuisances and Sensor Range Requirements

In Section C.6, an alert range of 75m was suggested, based on the diminishing returns (i.e., potential for reduction in harm) that result from longer ranges. Consider whether the in-path nuisance rates of Table 9 and Table 10 affect this recommendation. First, sensor range does not affect nuisance rates for the closing speed algorithm, so these results have no impact on a sensor range recommendation. Second, it was noted earlier that in-path nuisance alerts increase with sensor range for the algorithm using POV deceleration. These increase by an insignificant amount for the alert resulting from the imminent set of parameters, but more than double for the cautionary set. Section C.7.5, though, argued that with POV deceleration information, a parameter set chosen to give a “late” alert would provide both high potential for reduction in relative harm and a minimal number of in-path nuisance alerts. Therefore, since any alert using POV deceleration information is likely to be such an alert, results reported in this document do not suggest a significant influence on sensor range requirements from in-path nuisance alert rates.

C.8 Sensitivity of Simulation Results to Database and Model Assumptions

In this section the sensitivity of results to three model assumptions is explored. The three assumptions are: expected value of the POV deceleration, expected value of the SV braking intensity, and the assumption that important conclusions are largely independent of the day of database collection. Table 14 summarizes the studies; the following subsections report the work.

Table 14 Sensitivity Studies Performed

Variable	Result To Investigate	
	Potential for Reduction in Relative Harm	**In-Path Nuisance Alerts**
SV deceleration	No	Yes
POV deceleration	Yes	Yes
Database data: day of collection	Yes	Yes

C.8.1 SV Braking Intensity

In Section C.7, in-path nuisance alerts were defined as alerts occurring in situations in which “normal” braking is sufficient to avoid a collision. Normal braking for that section was described as having an upper limit described by a normal distribution with mean –0.25g and standard deviation 0.025g. Here the sensitivity to the in-path nuisance rates is examined when both of these model parameters are varied.

When the model is reduced to a fixed, deterministic braking level of 0.25g (i.e., the standard deviation is reduced to zero), the results are very similar to the original model. This is shown in the first two columns of Table 15, with the original model values in the second column and the values corresponding to zero standard deviation appearing in the first column. The six rows of data correspond to the two warning algorithms, each run with all three parameter sets.

Table 15 In-Path Nuisance Alert Rates per Million Braking Events Using Different Braking Intensity Models for the Following Car Driver

	Following Car Braking Intensity Distribution Mean and Std Dev (Normal distribution assumed. Resampled if draws are not between -0.12 and -0.40g)				
	Mean = -.25g Std dev = 0g	Mean = -.25g Std dev = .025g	Mean = -.27g Std dev = .025g	Mean = -.30g Std dev = .025g	Mean = -.35g Std dev = .025g
CAMP Closing Speed Warning Algorithm					
Imminent: 1.5sec RT, -0.5g decel	79.9	79.3	121	214	462
Intermediate: 1.5sec RT, -0.3g decel	185	187	294	490	964
Cautionary: 2.5sec RT, -0.3g decel	1,790	1,810	2,250	3,870	6,576
Warning Algorithm with POV Deceleration Information					
Imminent: 1.5sec RT, -0.5g decel	765	943	1,660	3,480	8,985
Intermediate: 1.5sec RT, -0.3g decel	21,500	21,700	32,700	46,100	61,990
Cautionary: 2.5sec RT, -0.3g decel	65,300	63,100	76,100	91,300	113,397

When the mean of the model is changed to reflect a higher tolerance for braking intensities not associated with threatening situations, the results are shown in the third, fourth, and fifth columns of Table 15. These numbers correspond to model means of –0.27g, -0.30g, and –0.35g. These values are thought to include a likely upper limit of braking considered to be within the realm of non-threatening situations. Reference [6] summarizes results from a 1940 study of braking levels [18] as follows:

Comfortable to passengers—preferred by driver: -0.27g.

Undesirable but not alarming to passengers—the driver would rather not use: -0.34g.

Severe and uncomfortable to passengers—driver classifies as an emergency stop: -0.43g.

Table 15 shows that as drivers view higher braking levels as being non-alarming, the number of in-path nuisances increases, as expected. The increase in the nuisance rate as the model mean changes from –0.25g to –0.35g varies from a five-fold increase for the imminent setting of the closing speed algorithm to a doubling for the cautionary setting of the algorithm which uses POV deceleration information. It is noted that in these braking events, the number of total alerts is not likely to change much. The “drivers” can simply avoid more impacts using only “normal” braking.

The study in this section suggests that if 0.25g is nearer the lighter end of what actual drivers consider a non-alarming event, then actual in-path nuisances can be expected to be higher than those reported in this paper, perhaps increasing by several times. Field trials with FCW systems will provide more reliable information. For now, we expect the in-path nuisance rates reported here to be a lower bound on the actual rates that would be experienced with deployed systems on the road.

C.8.2 POV Braking Intensity

REAMACS typically is used with a POV braking model that is a normal random variable with mean –0.17g and standard deviation 0.10g, as described in Section C.4.2. This section explores the effect on in-path nuisance rates when these POV braking levels are reduced to a mean of –0.10g and standard deviation 0.025g. The –0.10g rate for POV deceleration was chosen because it may approach the lower bound of actual lead car braking on highways. No higher deceleration rates are studied because it is thought that a mean of –0.17g is near the maximum likely to be typically found on highways. Table 16 shows results for both potential reductions in relative harm and in-path nuisance alerts for both warning algorithms and the cautionary and imminent parameter sets.

First, it is noted that the number of crashes that occur *without* the FCW is reduced dramatically by the lower POV deceleration rate from 70 to 4.4 PR crashes per million REAMACS braking events. This is because more time is available for the SV driver to react to the POV braking event. The level of braking required by the SV also decreases since the POV is not decelerating as hard. Table 16 shows that after lowering the POV braking intensity, the simulation yields an increase in the potential benefits of a FCW.

Table 16 shows also that the in-path nuisances, expressed per unit time (see, in Section C.7.6, "Estimated Exposure to In-Path Nuisance Alerts"), increase as well. The rates are indeed expected to increase, since the following car driver can brake less strenuously and avoid a crash, but the warning logic and settings are unchanged. For the closing speed-warning algorithm with the cautionary parameter setting, in-path nuisances per unit time increase by a factor of 27, from one in 4.5 years to one in two months. Likewise, if warnings include information of POV deceleration, the nuisance rate almost triples, from one in 6.8 weeks to one in 2.5 weeks. Clearly if POVs actually brake so that the mean rate is less than 0.17g, the upper limit on effectiveness will increase, as will the number of nuisance alerts.

Table 16 Sensitivity of Results to POV Deceleration Model: Potential for Reduction in Relative Harm and In-Path Nuisance Alert Rates.

(Cautionary parameter settings (2.5s RT, -0.3g decel))
(100m limit to Alert Zone)

	POV Braking Intensity Distribution Mean and Std Dev (Normal Distribution Assumed. Resampled if Draws are not Between-0.04 and -0.80g)	
	Less Deceleration than Standard Model Mean = -0.100g Std dev = 0.025g	Standard Model Mean = -0.170g Std dev = 0.100g
Potential for Reduction in Relative Harm		
Closing Speed algorithm.	99%	70%
Using Lead Veh Deceleration in warning algorithm	100%	90%
In-Path Nuisance Alerts per Driver-Year (see Section C.7.6 for method of computing)		
Closing Speed algorithm.	5.98 (1 in 2 months)	0.221 (1 in 4.5 years)
Using Lead Veh Deceleration in warning algorithm	21.2 (1 in 2.5 weeks)	7.69 (1 in 6.8 weeks)

C.8.3 Day of Database Collection

Two days of data are discussed – September 25, 1991, which is the data set that results in all other sections of this document are based upon, and July 11, 1993, which we use in this section for comparison. Reference [3] discusses this issue for REAMACS, and we mention those findings in this paragraph. That paper notes that in both days' data, about a quarter of the headway values are below one second. Traffic was heavier in the September data set, with slower traffic (median speed 54 mph, versus 61 mph for the July set) and smaller median gaps

(1.67 seconds, versus 1.97 seconds for the July set). In that study the July data produced 1/3 more crashes, and PR crashes comprised a higher percentage of the total. Effectiveness was found to be higher with a closing-speed type algorithm for the July data. Potential reduction in relative harm was 77%, versus 63% for the September data set when a 76m (250ft) sensor system was used, and an algorithm quite similar to the closing speed algorithm was used (with a "cautionary" level of parameter values).

In the work reported here, without a FCW in place, the September set results in 70 PR crashes per million REAMACS event, as reported earlier, and the July data set results in 112 PR crashes per million REAMACS events, an increase of 58%. The July data set also yields a higher mean impact speed, too: 13.7 mph versus 11.9 mph. Table 17 and Table 18 present simulation results for both days of the FHWA database. Again, the two warning algorithms studied in this paper are used, and for each algorithm, both the cautionary and imminent parameter sets are used. A 100m Alert Zone extent is assumed. The first column of each table presents the September data set results, which have already been presented and discussed in this report. The second column includes corresponding July data set results.

Table 18 presents potential reduction in relative harm results from REAMACS. First notice the results for the closing speed algorithm – those numbers in the first two rows of numerical values. With the closing speed algorithm, a significantly higher reduction in relative harm is found to be potentially available (assuming ideal compliance, etc.) for the July data set. This result is quite similar to that described in [3] and stated in the paragraph above, however there is a surprise in the second set of results in Table 17. While the potential for reduction in relative harm with the algorithm using POV deceleration and the cautionary parameters are used again is larger for the July data set than for the original September data set, when the imminent parameters are used, the opposite is true. A possible reason for the decrease in the estimated potential for reduction in relative harm with the imminent settings is that the July data set leads to generally higher impact speeds. Thus the imminent setting, which is a "later" alert, may not fare as well as the earlier cautionary alert in mitigating crashes in these scenarios.

Table 18 presents in-path nuisance results for the two days of database collection. The number of nuisance alerts decreases across the board when the July data set is used. This is consistent with the July data set having less tight headway and containing higher delta-velocities – braking events are likely to need more braking to avoid a crash.

So what conclusions can be drawn by comparing the two data sets? When both nuisances and the potential for reduction in relative harm are considered, the July data set yields results that the surface would argue more strongly for FCW development than the September data set: the potential for reduction in relative harm is estimated to be larger, and the number of in-path nuisances is predicted to be smaller. And yet it is the same highway. The real lesson, perhaps, is that the numbers *per se* depend upon the data set used, and so the specific quantitative results in this document should be used with great caution. Also, of course, it is desirable to obtain more data sets with a greater diversity of characteristics before using REAMACS to make fine distinctions between algorithms or parameter sets.

Table 17 Sensitivity of Results to Date of Traffic Data Collection: Potential for Reduction in Relative harm and In-Path Nuisance Alert Rates per Million Braking Events.

(100m limit to Alert Zone.)

	Date of Traffic Data Collection in FHWA Database	
	Sept 25, 1991 (This data used for all other studies)	July 11, 1993 (This data used only for this column in this table)
Camp Closing Speed Warning Algorithm		
Imminent: 1.5sec RT, -0.5g decel	20%	34%
Cautionary: 2.5sec RT, -0.3g decel	70%	80%
Warning Algorithm with POV Deceleration Information		
Imminent: 1.5sec RT, -0.5g decel	85%	80%
Cautionary: 2.5sec RT, -0.3g decel	90%	97%

Table 18 Sensitivity of Results to Date of Traffic Data Collection: In-Path Nuisance Alert Rates per Million Braking Events.

(100m limit to Alert Zone.)

	Date of Traffic Data Collection in FHWA Database	
	Sept 25, 1991 (This data used for all other studies)	July 11, 1993 (This data used only for this column in this table)
CAMP Closing Speed Warning Algorithm		
Imminent: 1.5sec RT, -0.5g decel	79	38
Cautionary: 2.5sec RT, -0.3g decel	1,810	1,276
Warning Algorithm with POV Deceleration Information		
Imminent: 1.5sec RT, -0.5g decel	943	100
Cautionary: 2.5sec RT, -0.3g decel	63,100	57,917

C.9 Summary

The computer simulation tool REAMACS (Rear-end Accident Model and Countermeasure Simulation) has been extended and used to compute metrics of performance that would result from ideal deployment and usage of FCW systems]. The work reported here uses two primary metrics associated with rear-end countermeasure performance. First, the REAMACS simulation tool is used to estimate the *potential reduction in relative harm* that FCWs may provide. Relative harm is computed over a set of simulated rear-end crash scenarios, and is defined as the ratio of the sum of the squared impact speeds for a vehicle equipped with a FCW to the same metric computed for a vehicle without the FCW. Second the In-Path Nuisance Alert Code (IPNAC) tool computes a metric called the *relative frequency of in-path nuisance alerts* that addresses the nuisance alerts likely to accompany the deployment of FCWs. In-path nuisance alerts are alerts issued by a FCW in response to a POV located in the host vehicle's path in situations considered to be non-alarming by the driver.

Simulation studies are done using a warning algorithm based on closing speed and a simple model of driver reaction to an alert, and another algorithm which also uses information about the POV deceleration. Vehicle pair speed and headways collected from Interstate 40 near Albuquerque by the Federal Highway Administration (FHWA) are used as initial conditions for the simulation work. Although this is the best database available to CAMP, the degree to which the particular database characteristics influence the simulation results is unknown. Because the database does not include vehicle accelerations, there are no stopped vehicles, and the simulation crash set significantly under-represents the frequency of rear-end crashes with stopped POVs. The database also is only highway data and therefore cannot be assumed to represent vehicle pair characteristics of other roadway types. These caveats highlight the need for more data on actual vehicle-following and braking behavior to provide more accurate estimates of potential benefits of FCW deployment. The modeling work also assumes perfect sensing by the FCW system and 100% compliance of drivers to warnings. Nuisances and false alarms due to out of path objects or sensing errors are not treated either.

The results for potential reduction in relative harm reported in this document do not take into account the possible effect of nuisance alerts on the willingness of drivers to heed the warnings or even to use the system. Therefore the results reported here are only a first-order estimate of benefits, and probably an upper bound on the actual benefits that may occur with deployment. The key premise of CAMP, is the *realizable reduction in relative harm* which would result from the deployment of FCWs would depend not only on the apparent benefits, but also on the possible effect of nuisance alerts on the willingness of drivers to use a FCW and heed the warnings. The benefits accrued when considering this effect might be called "second-order" benefits. This estimation of second-order benefits is not done in this report, however the first-order results reported provide information that may be used with the results of the human factors studies currently underway to estimate a realizable reduction in harm.

It is found that a target sensor that can support warnings at a 75-meter range provides at least 94% of the potential reduction in relative harm estimated for a sensor with unlimited range. There is a potential for FCWs to reduce relative harm by up to 67 percent using only the cautionary crash alert proposed, along with a sensor that supports a 75 meter warning range. If used alone, an imminent crash alert, has a potential for only 20% reduction in relative harm – a warning of this type, used alone, occurs too late for much benefit with decelerating POVs. When lead vehicle information is considered, there is a potential to reduce relative harm up to 81% using a set of algorithm parameters corresponding to both the cautionary and imminent parameters, and a sensor that supports a 75 m warning range.

It is possible, however, that if simulation studies included a more accurate representation of the frequency of collisions involving stopped lead vehicles, a longer sensing range might be found to be beneficial.

An approach to categorizing all FCW alerts is suggested. In an observation there are more types of alerts than simply "nuisance" alerts and "helpful" alerts, and in fact, cases are shown where over 80% of all alerts are neither of these, but are perhaps "reinforcing" alerts issued in threatening situations in which the driver is already acting appropriately.

Estimates of the expected exposure of a driver to in-path nuisance alerts are sensitive to model assumptions regarding braking levels that drivers are comfortable using in situations they consider non-alarming. For the cautionary crash alert design suggested, a rough scaling analysis estimates that 28 in-path nuisance alerts for every rear-end crash with an impact speed of ten miles per hour or greater. This scales to one in-path nuisance alert per 4.2 years. For the imminent crash alert, simulation predicts 1.3 in-path nuisances per rear-end crash with impact speeds of at least ten miles per hour. Future experimental studies are needed to provide a more accurate "scaling" for use with the simulation results.

Simulation suggests that use of information about POV deceleration by a warning algorithm may improve performance of the FCW. Such information has the potential to increase the potential reduction in harm and to also reduce the need to tradeoff between reducing relative harm and increasing the in-path nuisance alert rate. By adding POV information to the imminent crash alert, the potential for reduction in relative harm increases from 20% to 81%, however, the corresponding in-path nuisance alert rate increases from 1.3 to 13.5 per rear-end crash with impact speed of ten miles per hour or more. By adding both POV deceleration information and varying the warning algorithm design; a potential reduction in relative harm nearly equal to that of the cautionary crash alert can be achieved. (79%) While the in-path nuisance rate drops from 28 to 2.3 alerts per rear-end collision, with impact speed of ten miles per hour or greater.

In practice, in-path nuisance alert rates may be different than reported here for warning algorithms that use lead vehicle deceleration information. There are two reasons. First, this work studies a particular class of such warning algorithms, which is those algorithms that assume the lead vehicle will continue braking at its current deceleration until it stops. The simulated situations, however, match this same scenario – the lead vehicle brakes completely to a stop. In practice, many nuisance alerts will occur for these algorithms when the lead vehicle brakes only momentarily, and so the in-path nuisance rate is likely to be higher in practice for this set of algorithms. Second, warning algorithms can use different assumptions about the future braking levels of the lead vehicle. These other algorithms are not studied here.

The 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. This conclusion is based on a proposed model that defines alarming situations by the braking levels necessary to avoid a collision.

Effects of the sensitivity of the computed results to model parameters representing both lead and SV deceleration magnitudes are presented. Differences in results created by using a different day's data set from the same highway are also presented. In both cases, in-path nuisance rates may change several-fold, and the reduction in harm values may shift as well. Sensitivity studies suggest cautious use of quantitative results from this report; results are best interpreted as indicative of the general magnitude and the qualitative dependence of results on parameters.

C.10 References

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APPENDIX D

EXPOSURE ESTIMATE PILOT STUDY

D INTRODUCTION

The out-of-path nuisance alert requirements for FCW systems refer to exposures similar to those experienced by typical drivers. No database or statistics were found for exposure rates for the types of objects referred to in the Functional Requirements Report. Some data was needed to help set the number of exposures used for testing.

In April 1998, CAMP staff performed a pilot study. The purpose of the pilot study was to get a ballpark estimate of exposures and to test a method that might be used for a more extensive data collection effort. This section summarizes the results of the pilot study.

Methodology

Initially we attempted to have a passenger count the roadside objects while the vehicle was driven on the designated route. This was found to be very difficult and error prone. Too many signs went by too fast.

A second method was tried using videotaping. A passenger vehicle was equipped with a videocassette recorder and camera. The camera was placed on the dashboard near the center, looking out the windshield. While recording, the vehicle was driven on a route that included highways, main roads, and residential streets in Farmington Hills, Michigan. The recording was played back several times at slow speed. A form was used to count the number of instances of each type of roadside object. Each time through the playback, two staff members each took responsibility for counting two, three or four different types of objects.

Route

The length of the entire route is about 16.5 miles. The route was as follows:

Start at the parking lot exit nearest to C.A.M.P.
Left onto Country Club Drive
Right onto Northbound Haggerty
Right onto Eastbound 12 Mile Road
U-Turn onto Westbound 12 Mile
Right onto entrance ramp to M-5
South on M-5 to 10 Mile road exit
Left onto Eastbound 10 Mile Road
Fork left onto Eastbound Shiawassee
Left onto Northbound Orchard Lake Road
Right onto the entrance ramp to Westbound I-696
Follow I-696 to the M-5 exit.
Right onto Northbound M-5
Right onto Eastbound 12 Mile Road
Right onto Southbound Haggerty
Left onto Country Club Drive
Finish at the entrance to the CAMP parking lot.

Collected Data

	Number of Instances			
Lanes (in the direction of travel)	**1**	**2**	**3**	**4+**
Small roadside signs	63	72	23	5
Large roadside signs	14	19	26	17
Metal light poles	3	19	7	3
Overhead signs	2	2	6	9
Overhead traffic signals	3	7	7	2
Mailboxes	23	4	3	0
Bridges	0	1	7	6
Construction barricades	49	14		2
Guardrails	4	7	5	6
Concrete barriers	0	2	5	3
Slow cars in adjacent lanes	0	1	0	0
Stopped or parked vehicles	4	0	14	2
Slow vehicles at same distance in both adjacent lanes	0	0	0	0
Retroreflectors in the road	0	0	0	0
U-turns	1	0	0	0
Debris in the lane	0	0	0	0

Several definitions are important:

- Small signs were those with no dimensions larger than 21 inches. These typically included no-parking signs and speed limit signs on surface roads.
- A single turning lane was not counted as a traffic lane. Two turning lanes, one for left and one for right, were considered equivalent to one traffic lane.
- The construction barricades included barrels and sawhorse style units. They were primarily in closely spaced groups ranging from 6 to 33 barricades in a group.
- Overhead traffic signals included hanging illuminated signs such as those for no left turn. When several signals and hanging signs were at the same distance, they were counted as one.
- Small clearance-height signs attached to overpasses were considered part of the bridges and not counted as overhead signs.
- Large signs attached to a bridge were counted separately from the bridges.
- Objects that were more than two lane widths from the side of the road were not counted.
- Slow vehicles were those estimated to be going at least 20 mph slower than the test vehicle.

Other Observations

For most of the roadside object types, there were no clear distributions for their distances from the traveled roadway. The only exception was mailboxes, which tended to either be very close to the traveled roadway or just on the other side of a shoulder.

There were concrete barriers in the median of limited access expressways that were very long (e.g., more than a mile). It may be necessary to estimate the distance for these, and guardrails, rather than just count their numbers.

Trashcans were found very near the roadside. Metal trashcans may be as significant as construction barriers for sources of out-of-path nuisance alerts. It may be advisable to add these to the items counted and to the objects used in the test procedures.

When the road was divided, a significant proportion of construction barricades, concrete barriers, guardrails, and small roadside signs occurred on the left side. It may be advisable to count how many of each type of object were on the left and right of the traveled roadway.

Some signs and their support structures only extended over one lane of a multi-lane roadway. Other signs were only over one lane but were supported on a trellis that passed over all lanes. It might be better to count bridges and trellises as overhead structures and to count the number of lanes each sign is over.

Exposure

Assumptions

A simple approximation would be to assume that vehicles traveling in lanes other than the right-most lane will not respond to roadside objects.

It seems reasonable to assume that traffic distributes evenly between lanes when more than one lane is available in the direction of travel.

Estimates

The following table was prepared as an example of how the collected data might be used. The table weights each count of instances by the number of lanes. The exposure per day is calculated based upon the typical weekly driving distance of 201 miles found in Horowitz (1986). The values are rounded to the nearest integer to reflect the low accuracy in all of the measurements.

	Weighted exposure in 16.5 miles	Exposure per day (28.7 miles)
Small Roadside Signs	108	188
Large Roadside Signs	36	63
Metal Light Poles	16	28
Overhead Signs	7	12
Overhead Traffic Signals	9	16
Mailboxes	26	45
Bridges	14	24
Construction Barricades	56	97
Guardrails	11	19
Concrete Barriers	3	5
Slow Cars in adjacent lanes	1	2
Stopped or Parked Vehicles in adjacent lanes	9	16
Slow Vehicles at same distance in both adjacent lanes	0	0
Retroreflectors in the road	0	0
U-Turns	1	2
Debris in the lane	0	0
Total	**297**	**517**

Conclusion

The pilot study demonstrated that it is feasible to collect videotape from which the required data can be extracted. Preliminary estimates for exposure rates were derived from the videotape. However, it is not clear how well these preliminary estimates match the results that would be found in a more extensive data collection. Future studies should improve the methods to insure that the mixes of highway vs. surface street and urban vs. suburban vs. rural streets reflect national driving distributions. Future studies should also improve the method for counting overhead objects, should have a separate count for objects on each side of the road, and, perhaps, should include metal trashcans.

APPENDIX E

EQUIPMENT LISTS AND PUBLIC ROAD TEST ROUTES

TABLE OF CONTENTS

E TEST EQUIPMENT

E.1 Test Equipment List for Test Methodology Validation Activities

The six tables below list equipment used during the testing that supported the validation of the objective test methodology. This equipment list supports the discussions in Chapter 7. (Note that human factors testing used different vehicles and equipment, as reported in Chapter 3). The equipment here is divided into four groups, a group for each test car and another for the GPS base station. Also listed are the test vehicles and the radios. Note that the video equipment was not necessary for the POV #2 group. Miscellaneous items used during test execution, such as traffic cones, are not listed.

SV Instrumentation	Manufacturer	Model	Cost
Power Inverter	Tripp Lite	PV400	$170
Power Supply	Radio Shack	22-127E	$30
Local Area Network	Black Box		$1,428
RF modem	REPCO, Inc.	RDNFSK6U6UC	$865
Dynamic Measurement Unit	Crossbow	DMU-6	$2,495
Chassis	National Instruments	SCXI-1001	$8,000
Global Positioning System	NovAtel	Propak II RT2 w/ 502 antenna	$20,145
Computer	Micron	TransPort XKE	$4,800
Video Recorder	Sony	SVO2100	$2,285
Monitor	Citizen	M329	$240
Camera	Elmo	MN42H CCD CC421E	$2,442
Total			$42,900

Table E-1 Instrumentation and Costs for Subject Vehicle

POV #1 Instrumentation	Manufacturer	Model	Cost
Power Inverter	Tripp Lite	PV400	$170
Power Supply	Radio Shack	22-127E	$30
Local Area Network	Black Box		$1,428
RF modem	REPCO, Inc.	RDNFSK6U6UC	$865
Dynamic Measurement Unit	Crossbow	DMU-6	$2,495
Chassis	National Instruments	SCXI-1001	$8,000
Global Positioning System	NovAtel	Propak II RT2 w/ 502 antenna	$20,145
Computer	Micron	TransPort XKE	$4,800
Video Recorder	Sony	SVO2100	$2,285
Monitor	Citizen	M329	$240
Camera	Elmo	MN42H CCD CC421E	$2,442
Total			$42,900

Table E-2 Instrumentation and Costs for POV #1

POV #2 Instrumentation	Manufacturer	Model	Cost
Power Inverter	Tripp Lite	PV400	$170
Power Supply	Radio Shack	22-127E	$30
Local Area Network	Black Box	LW0026A	$1,428
RF modem	REPCO Inc.	RDNFSK6U6UC	$865
Dynamic Measurement Unit	Crossbow	DMU-6	$2,495
Chassis	National Instruments	SCXI-1001	$8,000
Global Positioning System	NovAtel	Propak 3151RE w/ 501 antenna	$6,140
Computer	Micron	TransPort XKE	$4,800
Total			$23,928

Table E-3 Instrumentation and Cost for POV #2

GPS Base Station	Manufacturer	Model	Cost
Power Inverter	Power Star	POW200	$100
Power Supply	Interstate Batteries	12 Volt 7.0 AH	$115

GPS Base Station	Manufacturer	Model	Cost
Global Positioning System	NovAtel	Propak II STD w/ 503 antenna	$17,725
Tripod	SECO	5119	$835
Computer	Micron	TransPort	$4,800
Total			$23,575

Table E-4 Equipment and Costs for GPS base station

Radio Items	Manufacturer	Model	Cost
Unit One	NexTel	370i	$201
Unit Two	NexTel	370i	$201
Unit Three	NexTel	370i	$201
Unit Four	NexTel	370i	$201
Total			$ 804

Table E-5 Cost for miscellaneous communication equipment

Test Vehicles Items	Manufacturer	Model	Cost
Car One	Chevrolet	’97 Lumina White	$18,222
Car Two	Chevrolet	’97 Lumina Blue w/ Eaton Vorad microwave radar	$18,222
Car Three	Mitsubishi	‘96 Diamante w/ laser radar	$12,300
Truck One	Ford	’95 F-700 w/ 24’ bed, GVWR 18,000#	$915
Truck Two	Ford	’95 F-700 w/24’ bed, GVWR 18,000#	$915
Motorcycle	Honda	’84 Nighthawk 650cc	$340
Total			$50,914

Table E-6 Vehicles used in executed tests

E.1.1 Computer Equipment

Micron TransPort™ XKE Systems

- TransPort XKE specifications
- Motherboard: 266MHz Intel Pentium® MMX P55CLM processor
- Notebooks
- Intel(R) PCI 430TX Chipset

  - 512K L2 pipeline burst cache
  - 60ns EDO RAM (Two user accessible 144-pin SO DIMM slots. Expandable by user to 192MB.) The TransPort XKE comes 64MB of memory on the motherboard depending on how it is ordered. The amount of memory on the motherboard cannot be changed.
  - Phoenix BIOS that can be flash upgraded.
- Video display specifications:
  - 128 bit graphics accelerator
  - NeoMagic NM2160 video controller
  - Video memory 2MB EDO DRAM
  - Supports hardware MPEG
  - LCD screens:
    - 12.1" TFT SVGA LCD color display
      + 640x480 65,536 colors
      + 800x600 65,536 colors (Recommended setting)
      + 1024x768 256 colors
    - 13.3" TFT XGA LCD color display
      + 640x480 65,536 colors
      + 800x600 65,536 colors
      + 1024x768 256 colors (Recommended setting)
- External monitor:
  - 640x480 16,777,216 colors at 85Hz non-interlaced
  - 800x600 16,777,216 colors at 85Hz non-interlaced
  - 1024x768 65,536 colors at 75Hz non-interlaced
- Television output: The TransPort XKE can be used with televisions sets that accept National Television Standards Committee (NTSC) output or televisions sets that accept PAL output. The NTSC standard is used throughout North America while the PAL standard is used in many European countries.

Internal Bays

The TransPort XKE has two internal bays facing the front of the machine that are designed to hold modular peripherals or batteries. As you face the computer the left modular bay can hold a battery or floppy disk drive. The right modular bay can hold a battery, a CD-ROM drive, or a hard disk drive. If a peripheral is put in the wrong bay the computer does not recognize it. The

TransPort XKE has an internal hard disk drive. Putting a hard disk drive in the right modular bay allows you to have two hard disk drives in the computer at the same time.

Hard Disk Drives

The TransPort XKE uses a removable internal hard disk drive with an EIDE interface. Acceptable drives must have a 2.5-inch platter and be 19mm or less in height. Detailed specifications for the hard disk drives available with the TransPort XKE computer can be found by going to the TransPort XKE in the Micron Technical Support notebook section and then going to Hard Disk Drives. The hard disk drive is removable from the TransPort XKE by taking out one screw in the bottom of the case.

Floppy Disk Drive

The TransPort XKE has a modular 1.44MB 3.5-inch floppy drive that fits in the computer's left side internal modular bay.

CD-ROM Disk Drive

The TransPort XKE has a modular 5.25-inch CD-ROM drive that fits in the computer's right side internal modular bay. Detailed specifications for the CD-ROM drives available with the TransPort XKE computer can be found by going to the TransPort XKE in the Micron Technical Support notebook section and then going to CD-ROM Drives. The TransPort XKE CD-ROM drive can be used to play audio CDs without turning on the computer. When a headphone plug is inserted into the headphone jack on the CD-ROM player the CD-ROM player turns on but the rest of the computer remains off. Note the headphones must be inserted into the jack on the CD-ROM player. If the headphones are installed in the headphone jack on the back of the computer the CD-ROM player will not work unless the computer is turned on.

Built-in Modem

The TransPort XKE has a built-in 33.6 data/fax Motorola modem.

- Data mode: Full-duplex
- Fax mode: Half-duplex
- Interface: Enhanced 16550 serial port emulation
- Transmit level: -10dbm at modem (permissive RJ11/CA11 or equivalent jack)
- Receive level: Dynamic range -38 dbm
- Power: Average 200ma in active mode, 60ma in sleep mode
- Data Connect Rates:
    - Up to 56Kbps receive only (requires a software upgrade)

    - Up to 33.6Kbps transmit and receive
    - Auto fallback rate from 33,600 bps to 300bps
- Data standards conformance
- ITU-T:
    - V.34: 33,600-2400
    - V.32terbo: 19,200, 16,800 (TCM)
    - ITU:
    - V.32bis: 14,400, 12,000, 7200 (TCM)
    - V.32: 9600 (TCM), 4800 (QAM)
    - V.22bis: 2400 (QAM)
    - V.22: 1200 (DPSK)
    - V.21: 300 (FSK)
    - V.23: 600/75, 1200/75 (FSK)
    - Bell 212A: 1200 (DPSK)
    - Bell 103: 300 (FSK)
- Fax standards conformance:
- Compatibility interface EIA-578 (Asynchronous Facsimile Modem Control Standard, Service Class 1 and Class 2)
- ITU:
    - V.17: 14,400, 12,000, 9600, 7200, (TCM)
    - V.29: 9600 (QAM), 7200 (QAM)
    - V.27terbo: 4800 (DPSK), 2400 (DPSK)
    - V.21 Channel 2: 300 (FSK)
- Data compression: V.42bis and MNP5
- Error correction: V.42 (MNP2-4)
- Cellular error correction: Enhanced Throughput Cellular (ETC)
- Operating temperature: 32 to 122 degrees Fahrenheit / 0 to 50 degrees Celsius
- Operating humidity: 10% to 90% non-condensing
- Connector: Standard RJ-11 connector and cellular phone connector
- Voice modem: Supports independent speaker/mic positioning. Full duplex speakerphone, echo cancellation gain maximum supported via IS-101 AT+V commands and extensions.
- Voice mode capabilities: TIA/EIA IS-101 AT+V voice command set. U-law, A-law, and linear voice data compression. IMA ADPCM compression at 8.0KHz, 16-bit.

External Connectors

- Cellular phone connector

- Fax/telephone connector for the built-in modem
- Universal Serial Bus (USB) connector (series A connector)
- Composite video jack. An RCA type jack used to connect the computer to a television set.
- S-Video 5-pin connector used to connect the computer to a television set. The S-video connector has separate output for red, green, blue, horizontal and vertical signals. It generally provides better quality television output than the composite video jack.
- 15-pin female Game/MIDI port
- 1/8 inch monaural microphone jack
- 1/8 inch stereo line-out jack (accepts stereo headphones)
- 25-pin female Centronics-standard bi-directional parallel port ECP/EPP
- 9-pin male serial port RS-232C, 16550AF compatible
- 2-way Infrared port on front of computer (can be used as either a wireless parallel or serial port). Supports both IrDA-I and IrDA-II, also known as Fast Infrared, for transfer rates up to 4,000,000bps (4Mbps).
- 2-way Infrared port on rear of computer (can be used as either a wireless parallel or serial port). Supports both IrDA-I and IrDA-II, also known as Fast Infrared, for transfer rates up to 4,000,000bps (4Mbps).
- 6-pin female mini-DIN PS/2 connector for an external PS/2 mouse
- 6-pin female mini-DIN PS/2 connector for an external PS/2 keyboard
- 15-pin female external VGA/SVGA monitor
- Proprietary port replicator connector
- Two PC Card (PCMCIA) slots. See PC Card specifications below.
- Kensington Security lock slot

Keyboard

- 87-key keyboard with cursor control keys, embedded numeric key pad, and 12 function keys.
- Connector for external PS/2 keyboard
- Hot Keys
  - Fn+F2 Switches between the LCD screen, an external monitor, or both.
  - Fn+F3 Switches between the pointing devices. Either the touchpad or the pointing stick can be active.
  - Fn+F4 Switches between the front and rear infrared ports.
  - Fn+F5 Decreases the volume of the onboard stereo speakers
  - Fn+F6 Increases the volume of the onboard stereo speakers
  - Fn+F7 Decreases the display brightness
  - Fn+F8 Increases the display brightness

  - Fn+F9 Puts the computer into suspend mode to save power. Pressing any key on the keyboard will take the machine out of suspend mode.
  - Fn+F10 Undock. When the computer is in the port replicator pressing Fn+F10 will prepare the computer to be removed from the port replicator. After pressing Fn+F10 wait for the safe undock light to come on and then it is safe to remove the computer from the port replicator.
  - Fn+F12 Internal PC speaker volume control. (Not to be confused with the two built-in speakers that run off the 16-bit sound card.) Volume can be set to high, medium, low, and off. The computer will give you an example beep at the set volume when you press the Fn+F12 keys.

Power Sources

Only use the Micron TransPort XKE power sources (AC adapter, batteries, and DC adapter) with the TransPort XKE notebook computer. Trying to use any other power adapter may damage the TransPort XKE notebook computer.

- AC adapter: The AC adapters supplied with the TransPort XKE notebook computer will switch voltages automatically when plugged into a 100 to 240 volt AC power source operating at a frequency of 50/60 Hz.
- Battery: Batteries are warm swappable. They can be changed while the computer is connected to an AC power source.
  - Smart Li-Ion Battery 5400 mAh
  - Battery status indicator built into the battery
  - Recharges in approximately 3.5 hours. When two batteries are installed in the computer the battery in the right modular bay will charge first and then the battery in the left modular bay will charge. The batteries are discharged in the reverse order. That is, the battery in the left bay will be discharged first and then the battery in the right bay will be discharged. To charge two batteries takes approximately seven hours.
- DC adapter for use in automobiles or airplanes

PC Card (Also Known as PCMCIA)

- TI PCI1131 PCI-to-PC Card controller
- Two PC Card slots. The slots will hold two Type I devices, or two Type II devices, or one Type III device. (A Type III device is so thick that when inserted into one slot it blocks the other slot.)
- Both slots are CardBus compatible
- Zoomed Video Support through the bottom PC Card slot

Pointing Devices

- Touchpad pointing device
- Stick pointing device
- Connector for external PS/2 mouse

Sound Specifications

- Built-in ESS1878 or ESS1879 sound controller (Sound Blaster 16 compatible)
- 16-bit stereo sound
- 1MB wavetable
- 32-voice FM synthesis
- 3D sound
- Two internal speakers 0.3 watts per channel
- Built-in monaural microphone
- Stereo line-out (allows use of stereo headphones)
- 15-pin female Game/MIDI port

Environmental Specifications

- Temperature
  - Powered on: 50 to 95 degrees Fahrenheit / 10 to 35 degrees Celsius
  - Powered off: 14 to 122 degrees Fahrenheit /-10 to 50 degrees Celsius
- Humidity
  - Powered on: 40 to 80 percent (no condensation)
  - Powered off: 40 to 80 percent (no condensation)

Dimensions and Weight

- TransPort XKE
  - 12.2 x 9.87 x 2.0 inches / 311 x 251 x 51 mm
  - 7.2lbs / 3240 grams (with one battery)
- TransPort XKE Lithium Ion Battery
  - 4.4 x 6.1 x 0.9 inches / 113 x 156 x 22 mm
  - 1.2lbs / 507 grams

Last Edited: 2-19-98

E.1.2 Signal Conditioning Extensions for Instrumentation (SCXI) Chassis

Product	Description	Cat. PG.	P/N	Qty	Price
SCXI Modules and Chassis					
SCXI-1200	DAQ and Control Module	3-165	776783-00	1	$895
SCXI-1120	8-Ch. Isolation Amp Module	3-175	776572-20	1	$1,195
SCXI-1141	8-Ch. Ellip. Lowpass Filter	3-187	776572-41	1	$1,795
SCXI-1181	SCXI Breadboard Module	3-224	776572-81	1	$1,95
SCXI-1001	SCXI 12-Slot Chassis	3-205	776571-01	1	$1,595
SCXI-1126	Freq. to Voltage Converter	371	776572-26	1	$1,295
Terminal Blocks, Cabling, and Accessories					
SCXI-1327	Attenuator Term. Block	3-212	776573-27	1	$295
SCXI-1320	Terminal Block		776573-20	1	$150
SCXI-1352	8-Ch. Cable from 1120 Out.	3-212	776573-04	1	$35
SCXI-1300	Low-Voltage Terminal Block	3-212	776573-00	1	$185
SCXI-1302	Feed through Terminal Block	3-212	776573-02	1	$175
SCXI-1360	Front Filler Panel	3-222	776576-60	7	$84
SCXI-1361	Rear Filler Panel	3-222	776576-61	10	$100
SCXI-1370	12-Slot Rack-Mount Kit	3-222	776576-70	1	$50

SCXI Chassis

SCXI-1000, SCXI-1000DC, SCXI-1001

Chassis house all SCXI modules
Low-noise environment for signal conditioning
- *Shielded enclosure*
- *Low-noise power system*

Rugged, compact chassis
- *Forced air cooling*
- *Optional rack mounting*

Integrated instrumentation system
- *3 internal analog buses*
- *Timing bus circuitry for high-speed module multiplexing*
- *Trigger lines for intermodule timing signals*

AC, DC, or battery power options

NI-DAQ Software
Windows NT
Windows 95
Windows 3.1
Mac OS
DOS

Application Software
LabVIEW
BridgeVIEW
LabWindows/CVI
LabWindows
Measure
ComponentWorks
VirtualBench
Lookout

Overview

The SCXI-1000, SCXI-1000DC, and SCXI-1001 are rugged, low-noise chassis. The SCXI-1000 and SCXI-1000DC can house up to four modules; the SCXI-1001 can house 12 modules. You can also daisy chain up to eight SCXI chassis with a single MIO board for high channel count applications.

The SCXI-1000DC is a DC-powered chassis that is ideal for portable applications or where standard AC power is unavailable. The SCXI-1000DC is powered by any 9.5 to 16 VDC battery or power supply, the optional SCXI-1382 battery pack, or the optional SCXI-1383 power supply/float charger.

The SCXI-2000, a four-slot chassis with built-in RS-232 and RS-485 serial interface, is also available for remote systems. See page 391 for more information on the SCXI-2000 chassis.

Description

The SCXI-1000, SCXI-1000DC, and SCXI-1001 chassis integrate the operation of an assortment of SCXI modules. The SCXIbus in the backplane of the chassis includes guarded analog buses for signal routing and digital buses for transferring data and timing signals. For example, you can use a plug-in DAQ board or an SCXI-1200 module to scan and acquire signals from multiple SCXI signal conditioning modules. In this operation, the SCXI chassis uses its SCXIbus to synchronize the digitization of the conditioned analog signal with the multiplexing and signal routing from the SCXI modules.

The SCXI chassis, along with the SCXI modules, are serially programmed using digital I/O lines of the DAQ board or SCXI-1200 module. The DAQ board or module programs the control circuitry of the chassis with the number and order of modules and channels to scan. Therefore, using SCXI will reserve up to four digital output lines and one digital input line of your DAQ board or SCXI-1200 module. Alternatively, an SCXI-2400 RS-232/RS-485 communications module can directly program the chassis via the SCXIbus.

Chassis	Slots	Power
SCXI-1000	4	AC
SCXI-1000DC	4	DC
SCXI-1001	12	AC
SCXI-2000[1]	4	AC
PXI-1010[2]	4/8	AC

[1] *SCXI-2000 includes an RS-232/RS-485 communications interface–(see page 391)*
[2] *PXI-1010 includes 4 SCXI slots and eight PXI slots–(see page 395)*

Table1. SCXI Chassis Options

The SCXI-1000 and SCXI-1001 are available with a number of standard AC power options. The SCXI-1000DC can be powered with any 9.5 to 16 VDC power supply. Optionally, you can use the SCXI-1382 12 VDC battery pack, or the optional SCXI-1383 power supply/float charger to operate the chassis from an AC power outlet.

Accessories

DC Power Accessories

The SCXI-1382 is a 12 VDC, 25 Ah battery pack that attaches directly to the SCXI-1000DC chassis. The SCXI-1382 can power a fully loaded SCXI-1000DC chassis for a minimum of 5 hours. The SCXI-1382 also includes a dual-stage battery charger, which charges a completely discharged battery in 8 to 11 hours. The dual-stage charger cannot power the SCXI-1000DC chassis. The SCXI-1383 is a 13.8 VDC, 4 A power supply/float charger for the

SCXI-1000DC. The SCXI-1383 will power the SCXI-1000DC from 115 VAC or 230 VAC power when DC power is unavailable. You can also combine the SCXI-1382 and the SCXI-1383 to operate in standby mode and provide uninterruptible power for the SCXI-1000DC chassis.

Chassis Accessories

The following rack-mounting and panel mounting hardware, filler panels, and a chassis handle are available for the SCXI-1000, SCXI-1000DC, and SCXI-1001 chassis. (See page 409 for more information.)

Mounting Options

Rack-Mounting kit for

SCXI-1001 ....SCXI-1370
SCXI-1000/1000DC SCXI-1371
two SCXI-1000/1000DC....................................SCXI-1372

Panel-Mounting for

SCXI-1001,1000, 2000DC.................................SCXI-1373

Chassis Handle..SCXI-1374

Filler Panels

Front filler panel...SCXI-1360
Rear filler panel..SCXI-1361

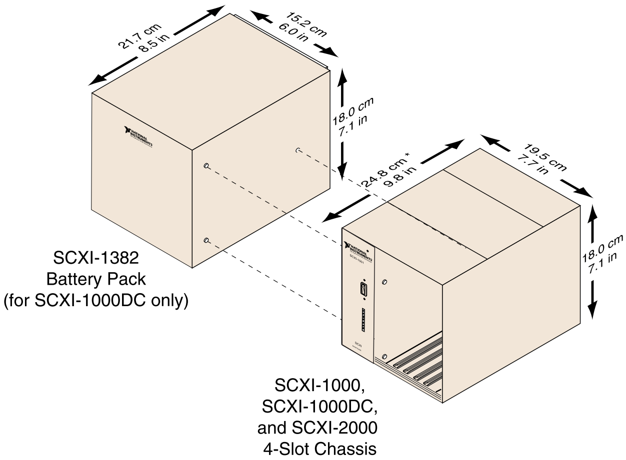
Part Numbers

SCXI-1000 4-slot chassis
U.S. 120 VAC 776570-01
Swiss 220 VAC 776570-02
Australian 240 VAC 776570-03
Universal Euro 240 VAC............................776570-04
No. American 240 VAC 776570-05
United Kingdom 240 VAC........................776570-06
Japan 100 VAC...776570-07
SCXI-1000DC 4-slot chassis 776570-00
SCXI-1001 12-slot chassis
U.S. 120 VAC 776571-01
Swiss 220 VAC 776571-02
Australian 240 VAC 776571-03
Universal Euro 240 VAC............................776571-04
No. American 240 VAC 776571-05
United Kingdom 240 VAC........................776571-06
Japan 100 VAC...776571-07
SCXI-1382 battery pack
without charger 776577-820
with 115 VAC charger* 776577-821
SCXI-1383 power supply/float charger
U.S. 120 VAC/Japan 100 VAC................776577-831
Swiss 220 VAC 776577-832
Australian 240 VAC.................................776577-833
Universal Euro 240 VAC..........................776577-834
No. American 240 VAC 776577-835
United Kingdom 240 VAC......................776577-836
SCXI-1360 front filler panel...............................776576-60
SCXI-1361 rear filler panel 776576-61
SCXI-1370 rack-mount kit
for SCXI-1001 776577-70
SCXI-1371 rack-mount kit
for SCXI-1000/1000DC.............................776577-71
SCXI-1372 rack-mount kit
for two SCXI-1000/1000DC.......................776577-72
SCXI-1373 panel-mount kit 776577-73
SCXI-1374 handle kit..776577-74

* With U.S. style three-prong power plug.

Phone: (512) 794-0100 • Fax: (512) 794-8411• info@natinst.com • www.natinst.com

SCXI Chassis



* SCXI terminal blocks mounted to front of chassis will add 7.5 cm to the depth dimension.

Figure 1. SCXI-1000, SCXI-1000DC, SCXI-2000, and Battery Pack Dimensions

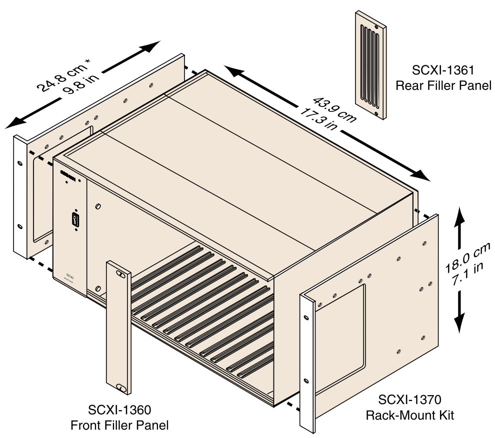


Figure 2. SCXI-1001 Dimensions

Figure 3. SCXI-1000DC, SCXI-1382 Battery Pack and SCXI-1374 Handle Accessory

Specifications

Typical for 25º C unless otherwise noted.

SCXI-1000, SCXI-1000DC, and SCXI-1001 Chassis

Power Requirements

Input voltage	
SCXI-1000 and SCXI-1001	*100, 120, 220, or 240 VAC at 50 or 60 Hz*
SCXI-1000DC	*12 VDC nominal (9.5 to 16.0 VDC)*
Operating current, maximum	
SCXI-1000	*0.6 A at 100 VAC* *0.5 A at 120 VAC* *0.25 A at 220 or 240 VAC*
SCXI-1000DC	*5.5 A (at 9.5 VDC)*
SCXI-1001	*1.25 A at 100 or 120 VAC* *0.7 A at 220 or 240 VAC*
Module power	
+5 V	*50 mA per slot;*
+18.5 to +25.0 V	*170 mA per slot;*
-18.5 to -25.0 V	*170 mA per slot*

Physical

Dimensions (including fan)[1]	
SCXI-1000 and SCXI-1000DC	*18.0 by 19.5 by 24.8 cm* *(7.1 by 7.7 by 9.8 in.)*
SCXI-1001	*18.0 by 43.9 by 24.8 cm* *(7.1 by 17.3 by 9.8 in.)*
Weight	
SCXI-1000	*3.9 kg (8 lb 10 oz)*
SCXI-1000DC	*3.3 kg (7 lb 5 oz)*
SCXI-1001	*6.8 kg (14 lb 14 oz)*

SCXI-1382 Battery Pack

Battery output	*12 VDC, 25 Ah*
Battery type	*Sealed lead-acid*
Minimum run time	*5 h (with four SCXI modules)*
Recharge time	*8 to 11 h (with included charger)*
Input power connection	*3 screw terminals, or connector*
Dimensions	*18.0 by 15.2 by 21.7 cm* *(7.1 by 6.0 by 8.5 in.)*
Weight	*8.6 kg (19 lb)*

SCXI-1383

Output voltage	*13.8 VDC at 4 A load*
Input voltage	*115/230 VAC at 60/50 Hz*
Dimensions	*16.5 by 8.0 by 5.7 cm* *(6.5 by 3.2 by 2.2 in.)*

Environment (all products)

Operating temperature	*0ºto 50º C (0º to 40º C for SCXI-1383)*
Relative humidity	*5% to 90% noncondensing*

Certifications and Compliances

CE Mark Compliance CE

This product meets applicable EU directive(s) as follows:

Safety isolation	*Low voltage directive EN 61010*
EMC Directive	
Immunity	*EN 50082-1:1994*
Emissions	*EN 55011:1991 Group I Class A at 10 m*

[1] *Dimensions do not include terminal block mounted to front of chassis, which will add 7.5 cm to depth*

Phone: (512) 794-0100 • Fax: (512) 794-8411• info@natinst.com • www.natinst.com

DMU 6X:
Silicon Inertial Measurement Unit

X, Y, Z, Acceleration, Roll, Pitch, Yaw, Angular Rates
DSP Processing Power
Analog & Digital Output
No Calibration Required

The DMU 6X is an intelligent six axis measurement system designed for accurate acceleration and angle measurement in dynamic environments. The DMU 6X employs a high performance Digital Signal Processor to provide outputs that are compensated for deterministic error sources within the unit. Internal compensation includes offsets, scale factors, and alignment. All six of the DMU-6X sensor elements are micro-machined devices. The three angular rate sensors consist of vibrating plates that utilize the Coriolis force to output angular rate independently of acceleration. The three MEMS accelerometers are surface micro-machined silicon devices that use differential capacitance to sense acceleration. The DMU-6X has analog and two digital output modes that allow for easy integration. In **voltage mode**, the analog sensor signals are sampled and converted to digital data with 1mV resolution. In **scaled sensor mode**, the analog sensor signals are sampled, converted to digital data, compensated, and scaled to engineering units. Digital data may be requested via serial command or to be transferred continuously.

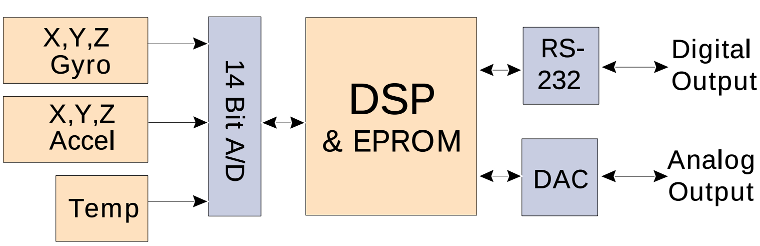


Figure 1. Block diagram of DMU-6X

DMU Products	Description	Output
DMU-6X	Direct digital voltage and signal conditioned analog outputs. Also outputs calibrated engineering units.	XYZ Acceleration 3 Axis Angular Rate
DMU-VGX	Tilt angle (roll/pitch) is computed. -6X outputs also included.	Roll & Pitch XYZ Acceleration 3 Axis Angular Rate
DMU-DG	XYZ Acceleration,3 Axis Angular Rate, 3 Axis Magnetometer	Roll, Pitch, Yaw
DMU-FOG	High accuracy tilt angle (roll/pitch) is computed. -6X outputs also included.	Roll & Pitch XYZ Acceleration 3 Axis Angular Rate

Table 1. Description of DMU Products

ORDERING INFORMATION

Part# BASE PART		Price 1-9
DMU-6X	Dynamic Measurement Unit	CALL

Note: Please specify the desired rate (50 - 150°/S) and acceleration (1-50 G) range when ordering.

DMU 6X:
Silicon Inertial Measurement Unit

DMU-6X Specifications

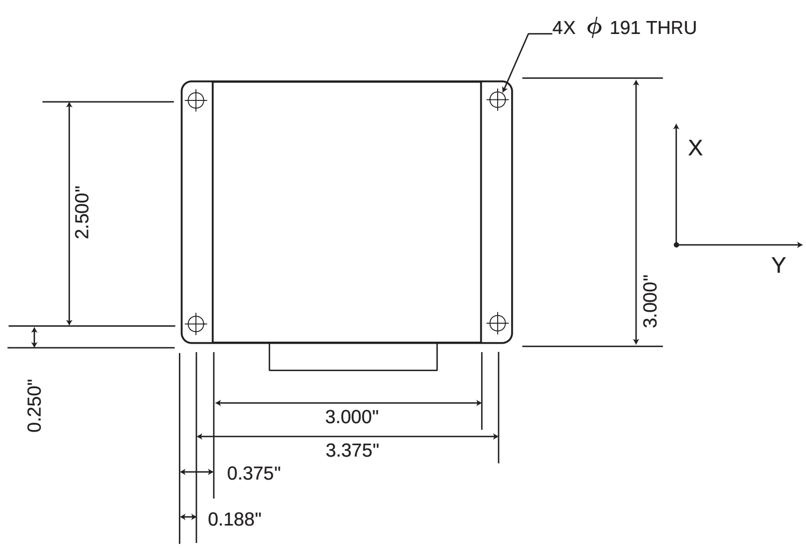
Performance	Gyro	Acceleration
Available Full Scale Ranges	±50, 100, 150° /S	±1, 2, 4, 10, 25, 50G
Full Scale Span (analog outputs)	±2.0V	±2.0
Full Scale Span (digital output)	-32,768 to 32,767	-32,768 to +32,767
Scale Factor Calibration	< 1 %	<1%
Bandwidth	DC - 10 Hz	DC - 100Hz
Linearity	0.5% of FS	0.2% of FS
Bias Stability (Room)	±1 °/sec	±70 mG
Bias Stability (-40 to 85)	±9 °/sec	<1°
Alignment (to enclosure)	<1°	
Resolution	0.05 °/sec	5 mG (FS < 8G), 50mG (FS > 8G)
Power		
Input Supply Voltage	8 - 30 VDC	
Input Supply Current	100 mA (max)	
Environmental		
Operating Temperature Range	-40 to 85°	
Storage Temperature Range	-55 to 85° C	
Package	Aluminum housing	
Weight	475 grams	
Mechanical Shock	1000 G (1 ms half sine wave)	
Vibration	10 G RMS	
Digital Data Output Rate		
Voltage Mode	166 Hz	
Scaled Sensor Mode	156 Hz	
Analog Mode	400 Hz	

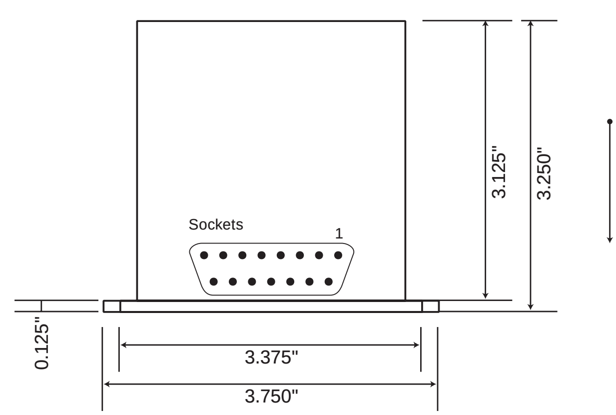
	Voltage Mode 12 bit, unsigned	**Scaled Sensor Mode** 16 bit 2's compliment
0	Header (255)	Header (255)
1	Gyro Voltage X (MSB)	Roll Rate, X (MSB)
2	Gyro Voltage X (LSB)	Roll Rate, X (LSB)
3	Gyro Voltage Y (MSB)	Pitch Rate, Y (MSB)
4	Gyro Voltage Y (LSB)	Pitch Rate X (LSB)
5	Gyro Voltage Z (MSB)	Yaw Rate, Z (MSB)
6	Gyro Voltage Z (LSB)	Yaw Rate, Z (LSB)
7	Accelerometer Voltage X (MSB)	Acceleration X (MSB)
8	Accelerometer Voltage X (LSB)	Acceleration X (LSB)
9	Accelerometer Voltage Y(MSB)	Acceleration Y (MSB)
10	Accelerometer Voltage Y (LSB)	Acceleration Y (LSB)
11	Accelerometer Voltage Z (MSB)	Acceleration Z (MSB)
12	Accelerometer Voltage Z (LSB)	Acceleration Z (LSB)
13	Temp Sensor Voltage (MSB)	Temp Sensor Voltage
14	Temp Sensor Voltage (LSB)	(MSB)
15	Time (MSB)	Temp Sensor Voltage (LSB)
16	Time (LSB)	Time (MSB)
17	Checksum	Time (LSB)
18		Checksum

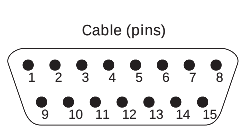
Data Packet Format (v1.2)

Development Software

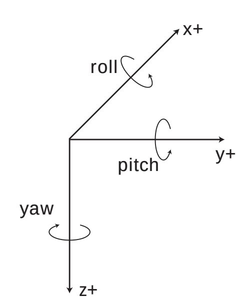
Crossbow's X-View software is shipped with DMU products for use on PC's running MS Windows '95. X-View provides a convenient way to start system development, evaluate the performance of the DMU, and perform data acquisition. Download a free copy from our website.







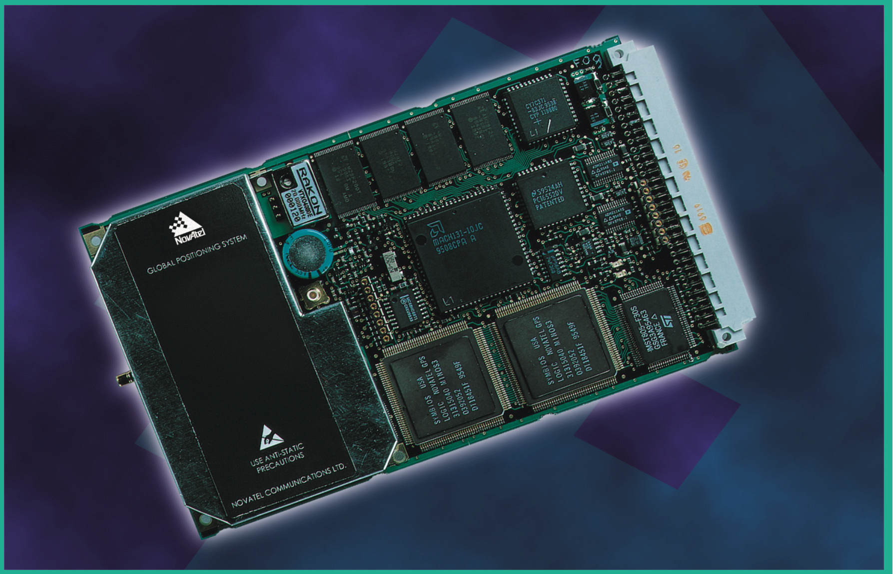
1	Transmit Data
2	Receive Data
3	Vcc
4	GND
5	X-axis Accelerometer Analog Voltage
6	Y-axis Accelerometer Analog Voltage
7	Z-axis Accelerometer Analog Voltage
8	Roll Rate Analog Voltage
9	Pitch Rate Analog Voltage
10	Yaw Rate Analog Voltage
11	Timing Pulse
12	Reset
13-15	GND/Unused



Crossbow

NovAtel

NovAtel's RT-2™ represents the pinnacle of high accuracy "real-time kinematic" (RTK) performance. Based on the 24 channel L1/L2 MiLLennium™ GPSCard, the RT-2 computes fixed integer carrier phase ambiguity estimates to deliver 2 cm accuracy in real-time. Fast and robust "on the fly" (OTF) initialization algorithms are employed to guarantee performance and ensure ease of use.



RT-2

NovAtel's RT-2 delivers high accuracy positions. Based on the MiLLennium GPSCard™, RT-2 applies the dual frequency advantage to deliver the most sophisticated RTK system available. Precision positioning based on fixed integer carrier phase ambiguity estimates provide nominal short baseline accuracy of two centimeters. Performance is extended to longer baseline applications through the use of dual frequency derived ionospheric corrections. Ease of use is guaranteed by fast and robust OTF initialization algorithms.

To address your integration requirements, RT-2's multiple hardware configurations provide you with the flexibility you need. Available modules include a single card OEM platform for embedded systems, and PowerPak™-II or ProPak®-II enclosures for standalone applications.

At NovAtel, our strength in developing performance GPS products is matched by our commitment to quality customer service.

We work hard to research and develop GPS technology which will give our customers the competitive advantage in business. Whatever your application, you can count on NovAtel's wide range of products and technical support to be your source for advanced GPS solutions.

Applications

- Mining and Machine control
- Survey/GIS
- Robotics
- Flight inspection
- Agriculture
- Marine/Dredging
- High precision OEM

Advantages

- 24 channel "all in view" parallel tracking
- L1-C/A code and L2-P code measurements
- L1 and L2 full wave carrier measurements
- Narrow Correlator® technology
- P-code tracking through Antispoofing (AS)
- 2 cm RTK accuracy
- High data output rates
- Low data latency
- Accurate and robust L1/L2 RTK with OTF
- Modest differential data link requirements
- RTCM message types 18, 19, 20 and 21
- Ionospherically corrected positions
- High dynamics
- Ease of use
- OEM or standalone configurations
- Flexible integration
- Upgradable

RT-2

NovAtel Inc.

1120 68th Avenue N.E.

Calgary, Alberta, Canada

T2E 8S5

1-800-280-2242
in U.S. & Canada or
(403) 295-4900

Fax: (403) 295-4901

Internet: http://www.novatel.ca
E-mail: gps@novatel.ca

NovAtel

Features

- 2 cm real-time kinematic (RTK) accuracy with "on the fly" (OTF) initialization
- L1-C/A code and carrier tracking
- L2-P card and full wavelength carrier tracking
- 24 channel "all in view" parallel tracking
- fast reacquisition
- patented Narrow Correlator technology
- 5 or 10 MHz external oscillator input
- 4 Hz position output rate
- 4 Hz raw data output rate
- 1 PPS output
- event marker
- RTCM SC104 v 2.1/2.2
- RTCA SC159
- RINEX v 2.0
- NMEA 0183 v 2.0
- GPSolution™ - Windows® compatible GUI

Specifications[1]

• position accuracy[2]	
stand alone	
SA off	15 m CEP
SA on	40 m CEP
differential	
code (L1, C/A)	0.75 m CEP
RT-2[3]	0.02 m CEP
• time to first fix	
cold start	70 s (typical)
• reacquisition	
warm start	3 s L1, 10 s L2 (typical)
• data rates	
measurements	4 Hz
position	4 Hz
• time accuracy	
SA off	50 ns RMS
SA on	250 ns RMS
• velocity accuracy	
stand alone	0.20 m/s RMS
differential	0.03 m/s RMS
• measurement precision	
C/A code	10 cm RMS
L2 P code	40 cm RMS
L1 carrier phase	
single channel	3 mm RMS
differential channel	0.75 mm RMS
L2 carrier phase	
single channel	5 mm RMS
differential channel	4 mm RMS
• dynamics	
acceleration	6 g
velocity[4]	515 m/s

OEMCard RT-2

• physical (Eurocard)	
size	17.7 cm x 10.0 cm x 1.7 cm
weight	175 g
• temperature	
operating	-40°C to +85°C
storage	-45°C to +95°C
• humidity	95% non-condensing
• interface	
dual RS232	300 to 115.2 Kbaud
strobe I/0	TTL level
external clock	5 or 10 MHz
• connector type	
edge	64 pin 0.1 " DIN 41612 type B
antenna	SMB male
external clock	SMB male
• input voltage	+5 VDC
• power consumption	8 watts

PowerPak II RT-2

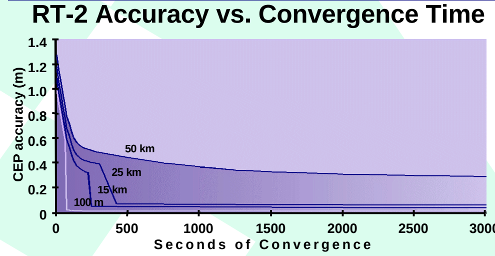
• physical	
size	21.0 cm x 11.1 cm x 4.7 cm
weight	980 g
• temperature	
operating	-40°C to +60°C
storage	-40°C to +85°C
• humidity	95% non-condensing
• interface	
dual RS232	300 to 115.2 Kbaud
strobe I/0	TTL level
external clock	5 or 10 MHz
• connector type	
communications	DE9P
strobes I/O	DE9S
antenna	TNC female
power	2.1 mm threaded plug
external clock	SMB male
• input voltage	10-36 VDC
• power consumption	11 watts
• accessories include	
RS232 "Y" type null modem cable	
automotive power cable	
• optional accessories	
110/220 Volt AC adapter	

ProPak II RT-2

• physical	
size	25.1 cm x 13.0 cm x 6.2 cm
weight	1.3 Kg
• temperature	
operating	-40°C to +55°C
storage	-40°C to +85°C
• humidity	95% non-condensing
• interface	
dual RS232	300 to 115.2 Kbaud
strobe I/0	TTL level
• connector type	
communications	10 pin LEMO
strobes I/O	8 pin LEMO
antenna	TNC female
power	4 pin LEMO
• input voltage	10-36 VDC
• power consumption	12 watts
• accessories included	
RS232 null modem and straight cable	
strobe I/O cable	
automotive power cable	
• optional accessories	
110/220 Volt AC adapter	

Typical Performance

RT-2 Accuracy vs. Convergence Time



For detailed product technical specifications, please call NovAtel's GPS Hotline (403) 295-4900.

1. *Specifications are subject to change without notice. Performance specifications are subject to GPS system characteristics & U.S. DOD operational degradation.*
2. *Accuracy is dependent upon ionospheric and tropospheric conditions, satellite geometry, baseline length and multipath effects.*
3. *See Typical Performance charts above.*
4. *Export licensing restricts operation to 60,000 feet maximum and 1,000 nautical miles/hour maximum.*

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NovAtel

NovAtel's family of GPS products includes the Performance Series – a range of advanced technology, high performance L1 GPSCards. These 12 channel "all in view" receivers feature NovAtel's patented Narrow Correlator® technology which provide sub-meter differential accuracy in real-time. High data output rates, fast signal reacquisition, and superior multipath mitigation techniques are designed to support even the most demanding GPS applications. Performance Series products are available in Eurocard, PC-Card and standalone configurations to provide flexible integration options.

AT NOVATEL, OUR STRENGTH IN DEVELOPING PERFORMANCE GPS PRODUCTS IS MATCHED BY OUR COMMITMENT TO QUALITY CUSTOMER SERVICE.

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Performance Series

NovAtel's PC Performance 3900 Series features a 2/3 length personal computer card designed for installation in PC compatible computers. This series offers a choice of two full DGPS Card models – the 12 channel 3911R, providing core functionality common to all GPSCard™ models, and the full data model 3951R.

NovAtel's OEM Performance 3100 Series features a Eurocard form-factor designed for standalone and embedded applications. This series offers a selection of GPSCard models ranging from the 12 channel 3111R, providing core functionality, to the advanced full data model 3151R. All OEM Performance Series receivers are DGPS capable and are rated for use at –40ºC to +85ºC temperatures. Available as a software option is NovAtel's Multipath Elimination Technology (MET®) which reduces pseudorange multipath error by a further 25% to 50% over NovAtel's existing multipath resistant Narrow Correlator.

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NovAtel ProPak® Performance 3100 Series provides a rugged water, shock and vibration resistant housing for outdoor applications which provides all the same functionality of PowerPak.

Applications

- DGPS Reference Station
- RT-20™ Reference Station
- Flight inspection
- Photogrammetry
- Survey/GIS
- Marine navigation
- High dynamics OEM

Advantages

- 12 channel "all in view" parallel tracking
- L1-C/A code and carrier measurements
- Narrow Correlator technology
- Multipath Elimination Technology (MET)
- Sub-meter real-time DGPS accuracy
- High data output rates
- Low data latency
- High dynamics
- Ease of use
- OEM, PC-Card, or standalone configurations
- Flexible integration
- Upgradable

Performance Series

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NovAtel

Features

- 1 meter real-time differential accuracy
- L1-C/A code and carrier tracking
- 12 channel "all in view" parallel tracking
- fast reacquisition
- patented Narrow Correlator technology
- optional Multipath Elimination Technology (MET)
- 10 Hz position output rate
- 20 Hz raw data output rate
- 1 PPS output
- event marker
- RTCM SC104 v 2.1/2.2
- RTCA SC159
- RINEX v 2.0
- NMEA 0183 v 2.0
- GPSolution™ - Windows® compatible GUI

Specifications[1]

• position accuracy[2]	
stand alone	
SA off	15 m CEP
SA on	40 m CEP
differential	0.75 m CEP
• time to first fix	
cold start	70 s (typical)
• reacquisition	
warm start	3 s (typical)
• data rates	
raw measurements	20 Hz
computed position	10 Hz
• time accuracy	
SA off	50 ns RMS
SA on	250 ns RMS
• velocity accuracy	
stand alone	0.20 m/s RMS
differential	0.03 m/s RMS
• measurement precision	
C/A code phase	10 cm RMS
Carrier phase	
single channel	3 mm RMS
differential channel	0.75 mm RMS
• dynamics (OEM Card Series only)	
acceleration	4 g
velocity[3]	515 m/s

PC Card 3900 Series

• physical	
size	21.6 cm x 10.7 cm x 1.9 cm
weight	220 g
• temperature	
operating	0°C to +70°C
storage	-40°C to +85°C
• interface	
PC ISA bus	8 bit/8 MHz
dual RS232 ports	
connectors	DB-9 male
baud rates	300 to 115.2 Kbaud
TTL Strobes I/O	DB-9 female
RF input	SMA female
• power consumption	6 watts

OEM Card 3100 Series

• physical (Eurocard)	
size	16.7 cm x 10.0 cm x 1.5 cm
weight	175 g
• temperature	
operating	-40°C to +85°C
storage	-40°C to +85°C
• humidity	95% non-condensing
• interface	
types	RS232/RS422/NMEA
baud rates	300 to 115.2 Kbaud
strobe I/0	TTL level
• connector type	
edge	64 pin 0.1 " DIN 41612 type B
antenna	SMB male
• input voltage range	5 VDC, ± 12 VDC
• power consumption	5 watts

PowerPak 3100 Series

• physical	
size	20.8 cm x 11.1 cm x 4.7 cm
weight	1 Kg
• temperature	
operating	-40°C to +65°C
storage	-40°C to +85°C
• humidity	95% non-condensing
• interface	
communications	RS232/RS422/NMEA
baud rate	300 to 115.2 Kbaud
strobe I/0	TTL level
• connector type	
communications	2 x DB9P
strobes I/O	DB9S
antenna	TNC female
power	2.1 mm threaded plug (center +)
• input voltage range	10-36 VDC
• power consumption	8 watts
• accessories include	
RS232 "Y" type null modem cable	
automotive power cable	
• optional accessories	
110/220 Volt AC adapter	

ProPak 3100 Series

• physical	
size	24.5 cm x 13.0 cm x 6.2 cm
weight	1.2 Kg
• temperature	
operating	-40°C to +65°C
storage	-40°C to +85°C
• humidity	95% non-condensing
• interface	
communications	RS232
baud rate	300 to 115.2 Kbaud
strobe I/0	TTL level
• connector type	
communications	2 x 10 pin LEMO
strobes I/O	8 pin LEMO
antenna	TNC female
power	4 pin LEMO
• input voltage range	10-36 VDC
• power consumption	8 watts
• accessories include	
RS232 null modem and straight cable	
strobe I/O cable	
automotive power cable	
• optional accessories	
110/220 Volt AC adapter	

For detailed product technical specifications, please call NovAtel's GPS Hotline (403) 295-4900.

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E.2 Public Road Test Routes

Table E-7 and Table E-8 describe the public road routes used to compare the objective test procedures with performance during typical driving. This supports Section 7.4.4. in Chapter 7. The tables include the miles traveled for each segment. The road type is designated as follows:

RI – Rural Interstate
RA – Rural Arterial
RL – Rural Local
UI – Urban Interstate
UA – Urban Arterial
UL – Urban Local

Table E-7 Nighttime Route for Public Road Validation of Test Methodology

	Road Type (and miles)					
NIGHT ROUTE	**RI**	**RA**	**RL**	**UI**	**UA**	**UL**
Start at end of ramp from M-5 south onto I-96 west						
I 96 west to Milford Road North	8.75					
Milford Road N. to GM Road East		4.2				
GM Road East to South Hill South (missed South Hill at first – made U-turn)			.48			
South Hill South to Buno East			2.23			
Buno E. to Old Plank North			.78			
Old Plank North to Oakland West			2.0			
Oakland West to River North			.5			
River North to Atlantic East			.3			
Atlantic East to Wixom Road South			.7			
Wixom Road South to Grand River East		7.8				
Grand River East to Shiawassee East					7.5	
Shiawasee East to Farmington Road North						.7
Farmington Road North to Ten Mile East						.35
Ten Mile East to Power South						.35
Power South to Grand River West (dogleg at Shiawassee)						.9
Grand River West to Farmington Road South						.52
Farmington Road South to Nine Mile East						.52
Folsom East (past Orchard Lake) to Base Line (Folsom turns south to become Randall)						1.79
Base Line East to Middlebelt Road North					.78	
Middlebelt Road North to Eleven Mile East					2.93	
Eleven Mile East to Franklin Road South					2.3	
Franklin Road South to Swanson East					.2	
Swanson East to Telegraph North					.1	

NIGHT ROUTE	Road Type (and miles)					
	RI	RA	RL	UI	UA	UL
Telegraph North to 696 West					.35	
I-696 West to Connector M-5 exit (12 mile road)				6.7		
End at end of ramp from M-5 to 12 mile road						
Total mileage for each road type:	**8.75**	**12.0**	**6.99**	**6.7**	**14.2**	**5.13**
Total Miles Night Drive:	**53.7**					

Table E-8 Daytime Route for Public Road Validation of Test Methodology

DAY ROUTE	Road Type					
	RI	RA	RL	UI	UA	UL
Start at end of ramp from M-5 south onto I-96 west						
I 96 West to Kensington Road North	11.9					
Kensington Road North to Pleasant Valley North (we took a wrong turn at Muir; U-turn back to Kensington Road)		2.2				
Pleasant Valley North to M-59 West		5.5				
M-59 West to Argentine Road South		5.7				
Argentine Road South to Golf Club West			2.0			
Golf Club West to Hughes South			.9			
Hughes South to Grand River East			2.3			
Grand River East to Hubert Road South		1.0				
Hubert Road South to Crooked Lake East (Herb Str.)			.7			
Crooked Lake East (Herb Str.) to Grand River East			1.0			
Grand River East to I 96 East		.6				
I 96 East to Hwy 23 South	2.3					
Hwy 23 South to Silver Lake Road East	2.4					
Silver Road South to Marshall Road South		1.25				
Marshall Road S. (becomes Spencer) to N. Territorial East			5.8			
N. Territorial East to Beck North		10.3				
Beck North to Eight Mile West		2.9				
Eight Mile West to Napier North		1.9				
Napier North to Nine Mile West			.9			
Nine Mile West to Griswold North			3.75			
Griswold North to Ten Mile West			.9			
Ten Mile West to Martindale North (short dogleg)			.3			
Martindale North to Grand River East			3.6			
Grand River East to Telegraph Road South					18.4	
Telegraph Road South to Michigan Avenue East					7.8	
Michigan Avenue East to Woodward South					11.0	

	Road Type					
DAY ROUTE	**RI**	**RA**	**RL**	**UI**	**UA**	**UL**
Woodward South to Jefferson South (Rt. Turn)						.22
Jefferson Ave. becomes Lodge (10) North; Lodge North to Clairmont Exit				5.0		
Hamilton North to Calvert West						.9
Calvert West to Byron North						.3
Byron North (doglag to Lincoln) to Sturtevant East						.7
Sturtevant East to Hamilton North						.08
Hamilton N. to Seven Mile Road West						2.88
Seven Mile Road West to Strathcona Northeast						.6
Strathcona Northeast to Woodward South						3.1
Woodward South to W. Grand Blvd. East (MI turn)					5.25	
W. Grand Blvd East to John R. South					.1	
John R. South to Warren Avenue West						1.0
Warren Avenue West to Trumbull South					.9	
Trumbull South to Alexandrine Southwest						.4
Alexandrine to Grand River West (Mulberry Selden)						.17
Grand River West to 14th Street Southeast						.35
14th Street Southeast to M. L. King Blvd. SW (?)						.52
M. L. King Blvd. SW to I 96 West						.44
I 96 West to I 94 East				1.05		
I 94 East to Van Dyke North				4.64		
Van Dyke North to Miller West					.31	
Miller West to Mt. Elliot Avenue North (Mt. Elliott turns into Mound)						.70
Mound North to I 696 West					6.86	
I 696 West to Woodward/Main				4.5		
Main North to Vinsetta Southeast						2.4
Vinsetta Southeast to Catalpa (cross Crooks, 12 Mile, & 2 Mich. Turns on Woodward)						1.5
Catalpa East to Washington South						.9
Washington South to Eleven Mile West						.5
Eleven Mile West to Woodward South					.5	
Woodward South to I 696 West					1.2	
I 696 West to Connector 5 exit (Twelve Mile & Haggerty)				14.2		
Twelve Mile East to Haggerty					.4	
End at intersection of 12 Mile and Haggerty						
Total mileage each road type:	**16.6**	**31.3**	**22.1**	**29.4**	**52.9**	**17.6**
Total miles daytime drive:	**170**					

E.3 Analysis of Uncertainty in Determining FCW Compliance with a Closing Speed-dependent Minimum Warning Range Requirement

E.3.1 Introduction

The following analysis was used to help select instrumentation for vehicle testing that was done to support the validation of the objective test methodology. For the alert onset timing requirements assumed at the time of testing, the analysis verified that the selected instrumentation would provide the ability to distinguish whether or not a FCW system issued an alert too soon or too late.

Chapter 7 (Section 7.2.2) specifies the following 3-sigma error on the ability to compare the FCW's warning range with the requirement on the warning range:

> Measure error between minimum allowed range of alert onset, and actual range at alert onset, to 5% of the min alert range, or 2.0m, whichever is larger.

The analysis in this section considers the possible error sources, assumes random process models for the sources, and estimates the resulting uncertainty in determining an FCW alert's timeliness. This analysis assumed that the requirement on minimum warning range depended only on the closing speed – the difference in speeds as a following vehicle approaches a slower-moving lead vehicle. **Therefore, to select instrumentation for the test procedures recommended in this final report, the analysis in this section would need to be updated, using the new statements about required alert onset timing (Chapter 4, Section 4.2).** This revised analysis would be similar to that reported here, but with a different expression used for the minimum required warning range.

E.3.2 The Performance Metric and its Error Sources

Let R denote the true range at onset of alert, and let R_{warn} denote the minimum required range for an alert, which depends on difference between the two vehicles' speeds: $\Delta V = V_{pov} - V_{sv}$. Then metrics of the FCW unit's compliance with the Task 3 minimum warning range requirements are based on the difference, ε_R, between the actual range and the minimum required range :

$$\varepsilon_R = R - R_{warn} \ .$$

where R_{warn} is the minimum required range for an alert, from Task 3, using constants a and RT:

$$R_{warn} = -\Delta V \cdot RT - \frac{\Delta V^2}{2a}$$

where Task 3 specifies the parameters as:

$$(RT,a)=\begin{cases}(1.5\text{sec}, -0.5\text{g}), & \text{imminent crash alert}\\(2.5\text{sec}, -0.3\text{g}), & \text{cautionary crash alert}\end{cases}$$

Consider errors in the computation of the metric ε_R that result from errors in measuring four variables:

R true range;

ΔV the range rate between the two vehicles, as defined above,

$\ddot{R}$ the relative acceleration of the POV away from the SV,

T_A the delay between the presentation of the alert to the driver and the moment at which the alert is logged into the data acquisition system.

Assume that the errors in measuring these variables are each zero-mean, independent errors with variances denoted by, for instance, $\sigma^2(\Delta V)$ for the variable ΔV. Then the three-sigma error in the computed value of the metric, denoted $\hat{\varepsilon}_R$, is a function of these three errors, as follows:

$$3\sigma(\hat{\varepsilon}_R)=\sqrt{\left(\frac{\partial\hat{\varepsilon}_R}{\partial R}\right)^2\cdot 3\sigma^2(R)+\left(\frac{\partial\hat{\varepsilon}_R}{\partial \Delta V}\right)^2\cdot 3\sigma^2(\Delta V)+\left(\frac{\partial\hat{\varepsilon}_R}{\partial \ddot{R}}\right)^2\cdot 3\sigma^2(\ddot{R})+\left(\frac{\partial\hat{\varepsilon}_R}{\partial T_A}\right)^2\cdot 3\sigma^2(T_A)}$$

where $3\hat{\sigma}(\varepsilon_R)$ is required by Section E.3.1 to be no greater than 5% of the warning range, or 2.0m, whichever is greater.

E.3.3 The Metric ε_R as a Function of the Four Variables

The metric is the difference between the range at the alert time, and the minimum range required at onset of the alert. Errors in the computed metric, $\hat{\varepsilon}_R$, come from two sources. First, measurements of range and range rate include measurement errors. Second, in general, the alert will not occur at the same instant that measurements of the subject vehicle's motion are collected. Thus, to compute the required minimum range at the instant of the alert, vehicle speed and range at the alert time must be estimated by propagating motion over a short time interval. The time of the alert, however, is not known exactly, and so the metric is in error. An expression for the metric that includes these two error sources is now developed.

Figure E-1 shows a timeline of events near the instant of an alert. Times t_A and $\bar{t}$ are the instants at which, respectively, the alert occurs and the vehicle motion measurements are collected. Vehicle motion measurements are range, $R(\bar{t})$, range rate $\Delta V(\bar{t})$, and relative acceleration between the vehicles, $\ddot{R}(\bar{t})$. The exact moment of the FCW alert is not known – it is assumed to be at time $\bar{t}-T_A$, but there is an uncertainty of $d(T_A)$. This uncertainty is quite small – perhaps 10 to 100 milliseconds – and is due to delays and finite sampling times both inside and outside the FCW unit under test.

The actual metric of the warning range performance is ε_R evaluated at time t_A, or $\varepsilon_R(t_A)$. Since time t_A is not known, the estimate of this metric, $\hat{\varepsilon}_R$, is computed by assuming that the alert occurs at time $\bar{t} - T_A$:

$$\hat{\varepsilon}_R = \varepsilon_R(\bar{t} - T_A) \ .$$

Then

$$\hat{\varepsilon}_R = R(\bar{t} - T_A) - R_{warn}(\bar{t} - T_A)$$

Assume that the actual relative acceleration between the two vehicles is constant during the interval under consideration. Then vehicle motion variables at the expected time of the alert are:

$$R(\bar{t} - T_A) = R(\bar{t}) - \Delta V(\bar{t}) \cdot T_A - \ddot{R}(\bar{t}) \cdot \frac{1}{2} T_A^2$$

$$\Delta V(\bar{t} - T_A) = \Delta V(\bar{t}) - \ddot{R}(\bar{t}) \cdot T_A \ .$$

The estimate of the metric is then:

$$\hat{\varepsilon}_R = R(\bar{t}) - \Delta V(\bar{t}) \cdot T_A - \ddot{R}(\bar{t}) \cdot \frac{T_A^2}{2} + \left(\Delta V(\bar{t}) - \ddot{R}(\bar{t}) \cdot T_A\right) \cdot RT + \frac{1}{2a}\left(\Delta V(\bar{t}) - \ddot{R}(\bar{t}) \cdot T_A\right)^2$$

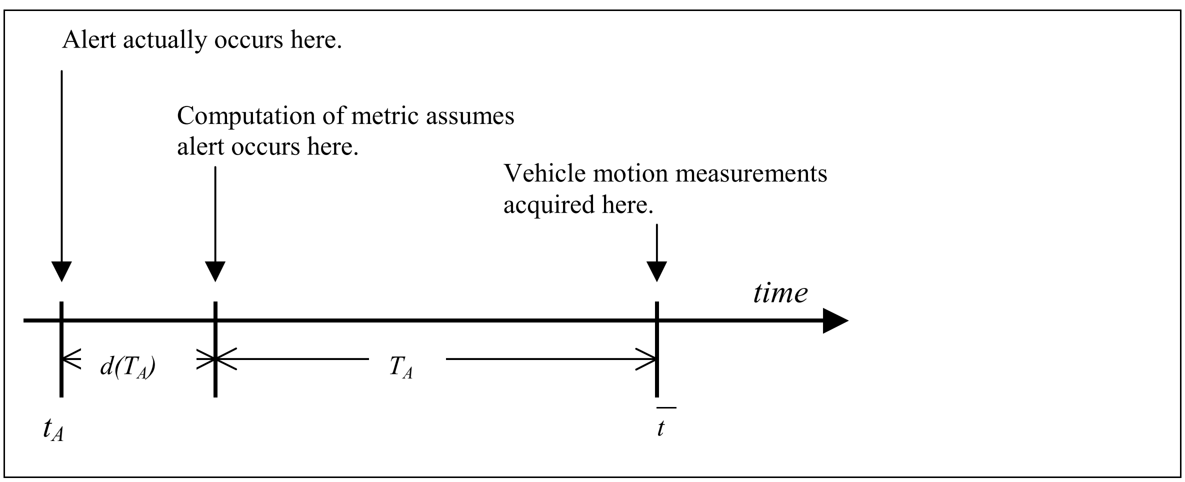

Figure E-1 Timeline of Events Near a Crash Alert

E.3.4 Partial Derivatives of the Metric

The partial derivatives of the computed metric $\hat{\varepsilon}_R$, taken with respect to the four variables, are shown in Table E-9.

Table E-9 Partial Derivatives of The Warning Range Performance Metric

$$\frac{\partial\hat{\varepsilon}_R}{\partial R} = 1$$

$$\frac{\partial\hat{\varepsilon}_R}{\partial \Delta V} = RT + \frac{\Delta V}{a} - T_A\left(1 + \frac{\ddot{R}}{a}\right)$$

$$\frac{\partial\hat{\varepsilon}_R}{\partial \ddot{R}} = -T_A\left(-\frac{1}{2}T_A + RT\right) - T_A\left(\frac{\Delta V}{a}\right) + T_A^2\left(\frac{\ddot{R}}{a}\right)$$

$$\frac{\partial\varepsilon_R}{\partial T_A} = -\ddot{R}\left(T_A + RT\right) + \left(\ddot{R}\right)^2\left(\frac{T_A}{a}\right) - \Delta V\left(1 + \frac{\ddot{R}}{a}\right)$$

Thus the error in evaluating the FCW's warning range performance, relative to the minimum alert range, depends on the following variables: the warning algorithm parameters, the relative speed and relative acceleration between the two vehicles, and the delay between the alert and the acquisition of data. It is independent of the true range itself. Because this error depends on these quantities, it will be necessary to verify that the requirement on the accuracy of the metric is met throughout the space of these variables.

E.3.5 Uncertainties in the Four Variables

Consider uncertainties in knowledge of the four variables, as shown in the table below. These values reflect the use of DGPS units on each vehicle (NovAtel Millenium RT-2). The range and range rate specifications for this unit are, respectively, 0.06m and 0.09m/sec 3-sigma. An easily obtainable spec for longitudinal accelerations is 0.10m/sec^2, or 0.01G. The time of the alert is given by the FCW units under test – a likely delay is 0.10 sec with an uncertainty of between 10 and 50 msec, based on discussions with the vendors. These numbers are shown in Table E-10 below.

Table E-10 Uncertainties in the Four Measured Variables

Variable	Uncertainty (3sigma)
R	0.06m
ΔV	0.09m/s
$\ddot{R}$	0.1m/s/s
T_A	0.050 sec

E.3.6 Computing Uncertainty in the Error Metric

The 3-sigma uncertainty in the computed metric $\hat{\varepsilon}_R$ is computed for nine crash scenario situations, using measurement uncertainties (Table E-10). Nine situations are used to verify that the uncertainty in the metric satisfies the requirement given in Chapter 7 (and at the top of this section) across all possible combinations of range rate, relative acceleration, and delay between alert and data logging, as stated earlier. Eight of the nine situations are the $2^3 = 8$ possible combinations of the minimum and maximum values likely to occur for each of the three variables. The ninth provides additional insight.

Consider first the cautionary crash alert. Table E-11shows results of computing the minimum required warning range and the 3-sigma error for the performance metric for nine different crash scenarios, using the uncertainties from Table E-10. The shaded rows show those cases for which the 3 sigma error is larger than 5% of the minimum required range. Note that all of these shaded rows have less than 2.0m of error, so that with these uncertainties, the requirement on the performance metric can be satisfied.

Table E-12 shows results of similar computations, except with the imminent crash alert parameter settings used. Again, the shaded rows indicate crash scenarios in which the 3-sigma error in the warning range metric exceeds 5% of the minimum required warning range. Because none of these values are greater than 2.0m, the requirement on the performance metric is satisfied.

Table E-11 Error in the Warning Range Performance Metric for Nine Crash Scenario Conditions

Independent 3 sigma errors assumed
$R\_$ = 0.06*sqrt(2) m
ΔV = 0.09*sqrt(2) m/sec
$\ddot{R}$ = 0.10 m/sec^2
T_A = 0.050 sec
Cautionary crash alert assumed

State	Warning Range (m)	3sigma of metric (m)	Ratio 3sig /Warn Range
ΔV = -5 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.10 sec	16.8	0.61	3.64%
ΔV = -27 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.10 sec	100	2.02	2.02%
ΔV = -27 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.10 sec	100	3.44	3.44%
ΔV = -5 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.10 sec	16.8	1.03	6.17%
ΔV = -5 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.25 sec	16.8	0.63	3.79%
ΔV = -27 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.25 sec	100	2.06	2.06%
ΔV = -27 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.25 sec	100	3.45	3.45%
ΔV = -5 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.25 sec	16.8	1.04	6.19%
ΔV = -15 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.25 sec	75.8	2.13	2.81%
ΔV = -5 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.0 sec	16.8	0.60	3.56%

Table E-12 Error in the Warning Range Performance Metric for Nine Crash Scenario Conditions

Independent 3 sigma errors assumed

$R\_ = 0.06$ *sqrt(2) m

$\Delta V = 0.09$ *sqrt(2) m/sec

$\ddot{R} = 0.10$ m/sec^2

$T_A = 0.050$ sec

Imminent crash alert assumed

State	Warning Range (m)	3sigma of metric (m)	Ratio 3sig /Warn Range
ΔV = -5 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.10 sec	10.1	0.43	4.24%
ΔV = -27 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.10 sec	100	1.63	1.63%
ΔV = -27 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.10 sec	100	2.57	2.57%
ΔV = -5 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.10 sec	10.1	0.72	7.15%
ΔV = -5 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.25 sec	10.1	0.45	4.43%
ΔV = -27 m/sec $\ddot{R}$ = 0 m/sec^2 T_A = 0.25 sec	100	1.65	1.65%
ΔV = -27 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.25 sec	100	2.59	2.59%
ΔV = -5 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.25 sec	10.1	0.73	7.28%
ΔV = -15 m/sec $\ddot{R}$ = -3 m/sec^2 T_A = 0.25 sec	45.5	1.57	3.46%

E.4 Minimum Required Sampling Rate for Onboard Data Acquisition System

This section describes the selection of the 20 Hz sampling rate for the data acquisitions systems onboard the SV and the POVs in the FCW evaluation tests. Table E-13 summarizes the data rate requirements for each measurement, along with the test scenario that drives each requirement and a brief summary of the rationale for the requirement. More details leading to the selection of each type of data rate follows the table.

The highest minimum required rate for onboard data acquisition by the instruments used to evaluate the FCW is 20 Hz. This requirement is driven by crash scenario tests in which one or more vehicles performs a lateral maneuver – the most severe of which is an 0.3g lane change. Since the onboard data acquisition system is to be as simple as possible, a 20 Hz rate will be used.

E.4.1 Longitudinal Position of SV, POVs, and Clutter

Two data rate requirements are computed here. A rate of 10 Hz is chosen.

First, consider a data acquisition rate that is driven by the highest possible bandwidth of longitudinal maneuvers. Range changes only through the low-frequency dynamics of the vehicles' longitudinal braking and/or accelerations. Assume the highest significant frequency in the dynamics from brake pedals to relative displacements is caused by the braking hydraulic system, which is modeled here as a first order system with a 0.150 sec time constant. Then choose a data rate of 5 samples per time constant, for a data rate of 33 Hz.

Second, assume that the test instructions include only step changes in brake pedal application, and assume that the range measurements of greatest interest are not within a second of a brake pedal application by either vehicle. Then accelerations will remain largely constant, and even with a relative acceleration of 0.5g, a 10 Hz rate would introduce an error in linear interpolation of measurements of $\frac{1}{2} \times 0.5 * 9.80 \text{m/s/s} * (0.10\text{s}/2)^2 = 0.012\text{m}$. Thus 10 Hz is quite sufficient under these assumptions.

E.4.2 Longitudinal Speed of SV and POVs

10 Hz. See discussion for item above.

E.4.3 Longitudinal Acceleration of SV and POVs

See discussion for item above.

E.4.4 Lateral Position of Clutter, Stationary POVs and Road

Survey locations once per setup of test site or "scene."

Table E-13 Minimum Required Data Acquisition Rates

Measurement	Minimum Data Rate Required	Test That Drives Data Rate	Data Rate Computed Based On:
Longitudinal position of SV,POVs, and clutter	10 Hz	Crash scenario tests (perhaps with braking by POV).	Assume constant relative acceleration (assume range not required during first 0.5sec of brake application). 10Hz gives 0.012m error in interpolating data for a 0.5g relative acceleration.
Longitudinal speed of SV and POVs	10 Hz	Crash scenario tests (perhaps with braking by POV).	Same as above
Longitudinal acceleration of SV and POVs	10 Hz	Crash scenario tests with braking by POV.	Same as above
Lateral position of clutter, stationary POVs and road	Once per setup of test site or "scene"	--	--
Lateral position of SV and moving POVs	4 Hz	Crash scenario tests with lateral manuevers	Available and affordable GPS units
Yaw rate of SV and POV	20 Hz	Crash scenario tests with lateral maneuvers	
Atmospheric visibility	Once per test trial when testing poor visibility performance.	Poor visibility test	--
SV brake pedal actuation time	10 Hz	Crash scenario tests: Need to know SV driver did not brake before alerts sounded.	Need for a finer resolution considered unlikely
Roadway horizontal curvature (direction change)	Once per test site	--	--
Roadway elevation change (for superelevation and vertical curvature)	Once per test site	--	--

E.4.5 Lateral Position of SV and Moving POVs

The required data acquisition rate for locating the SV laterally, as well as locating any moving POV laterally, is driven by lateral maneuvers during crash scenario tests. Assume that the dynamics of the steering wheel-to-lateral displacement and steering wheel-to-heading angle system has a 2 Hz bandwidth. Then the required data rate is estimated as ten times that bandwidth, or 20 Hz. The 20 Hz value is the highest required rate of all the measurements, and as such, it will drive data acquisition system definition.

The lateral position will be measured onboard each vehicle using onboard differential GPS units. The unit selected provides only a 4 Hz value, so a yaw rate sensor and accelerometers will be used to interpolate between the GPS data. The data rate for these must be 20 Hz to adequately capture the handling dynamics.

E.4.6 Yaw Rate of SV and POV

20 Hz. See discussion for item above.

E.4.7 Visibility

Atmospheric visibility measurements will be done once per trial of the poor visibility tests. This will capture the instantaneous visibility.

E.4.8 SV Brake Pedal Actuation Time

A 10 Hz rate will be sufficient to determine whether the SV driver brakes before the test is complete.

E.4.9 Roadway Horizontal Curvature (Direction Change)

Road geometry will be surveyed once per test site.

E.4.10 Roadway Elevation Change (For Super-Elevation And Vertical Curvature)

Road geometry will be surveyed once per test site.

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