DEVELOPMENT AND VALIDATION OF FUNCTIONAL DEFINITIONS AND EVALUATION PROCEDURES FOR COLLISION WARNING/AVOIDANCE SYSTEMS

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Development and Validation of Functional Definitions and Evaluation Procedures For Collision Warning/Avoidance Systems

Final Report

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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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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.

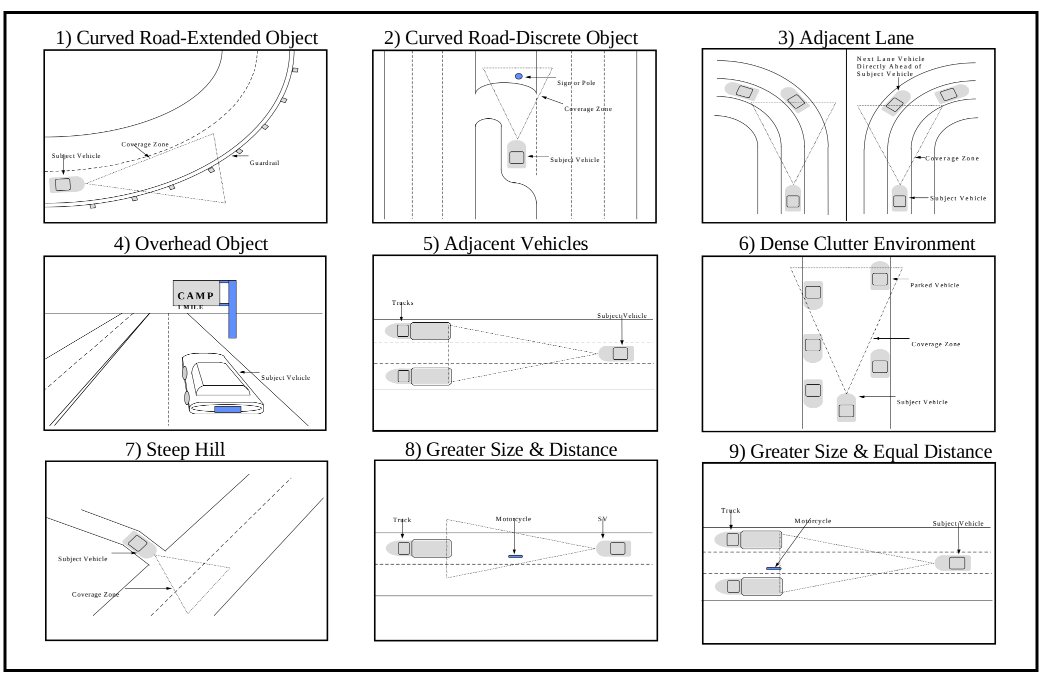
The specific crash problem which an FCW system should address is described in terms of the prioritized list of six rear-end crash scenario descriptions contained in Table 1. These scenarios were selected from previous analysis work ("44 Crashes", Version 3.0, General Motors, January 1997) which combined 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.

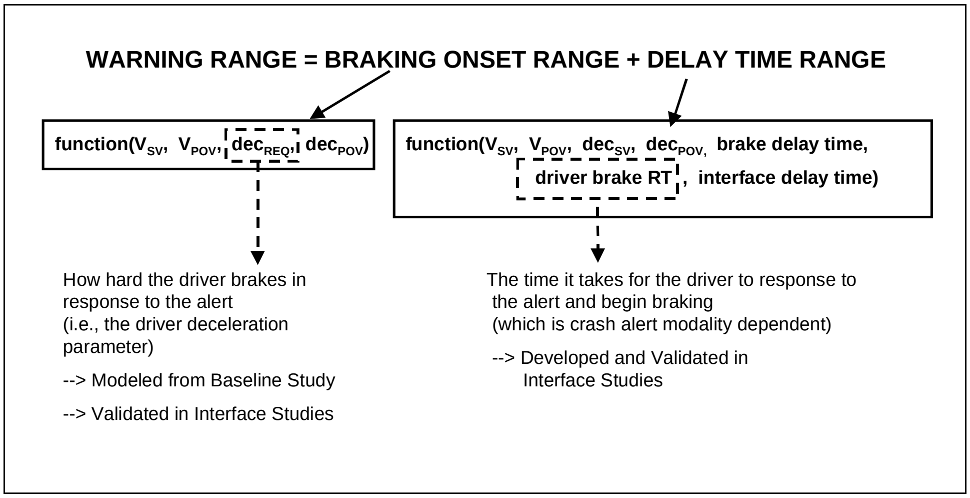


Figure 2 – Driver Behavior Parameter Influence on Warning Range

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.

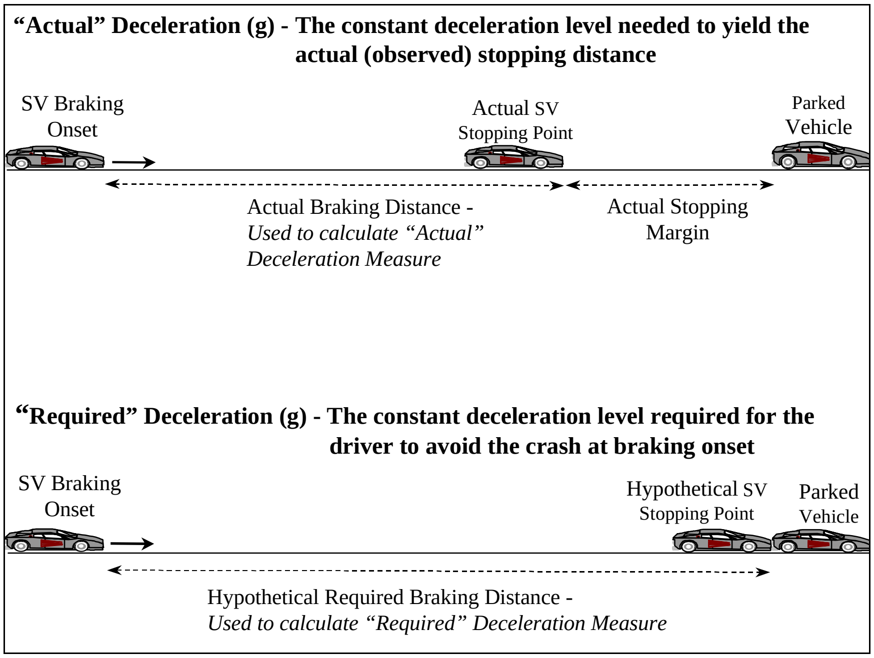


Figure 3 - Definition of Actual and Required Deceleration Measures

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.

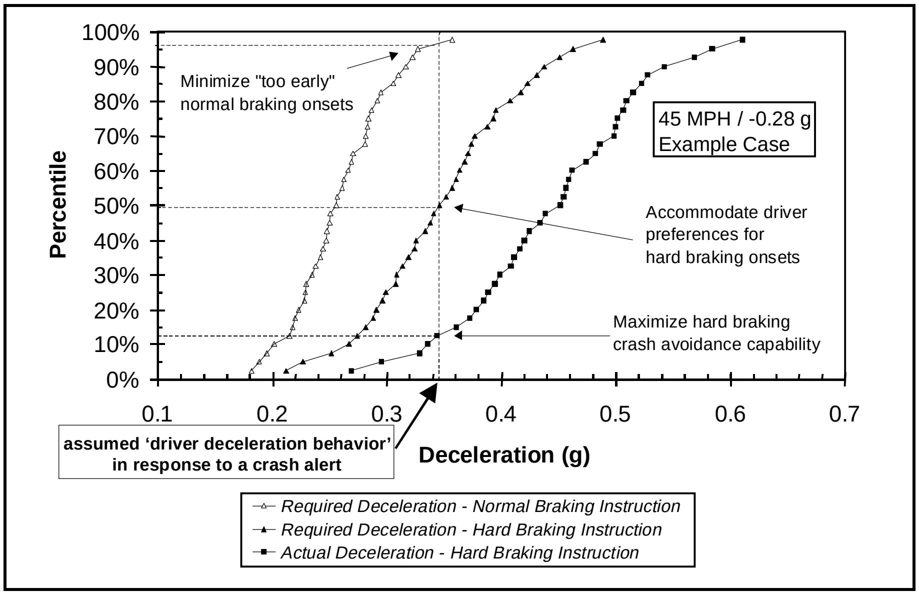


Figure 4 – Required Deceleration Model for Assumed Driver Deceleration Behavior

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.

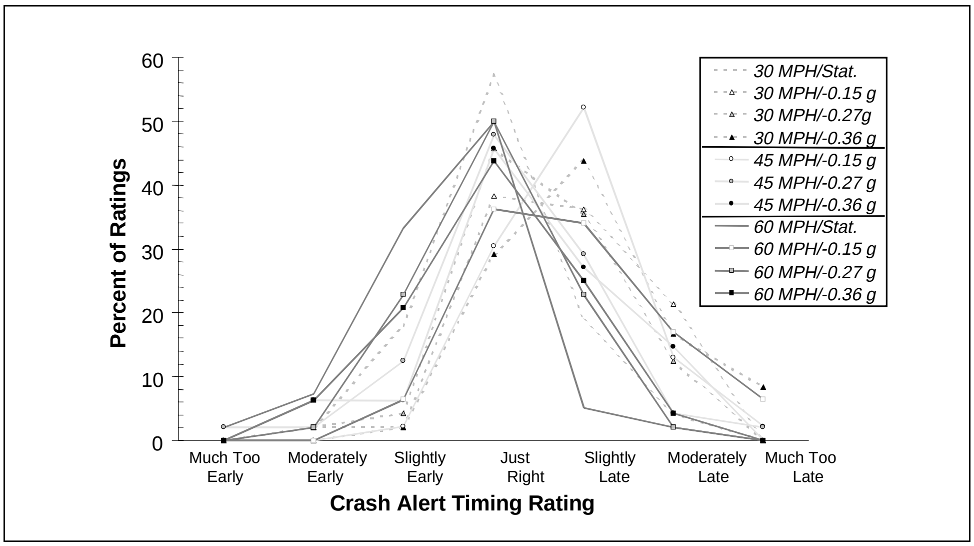


Figure 5 – Driver Subjective Ratings of Alert Timing for Alerted Trials

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.

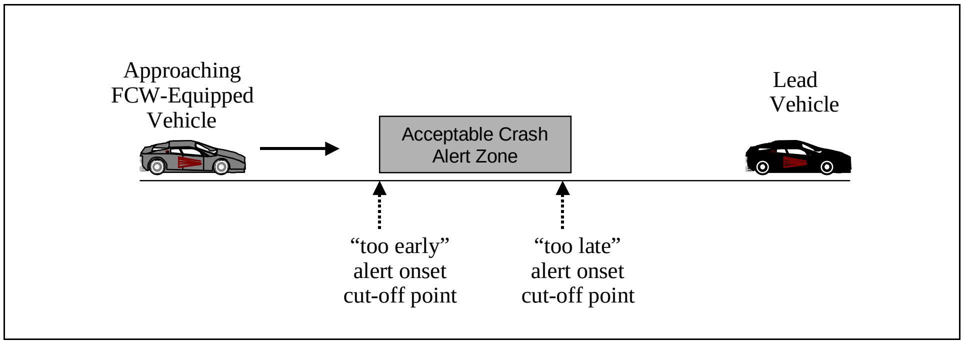


Figure 6 - Illustration of the Acceptable Crash Alert Timing Zone

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.

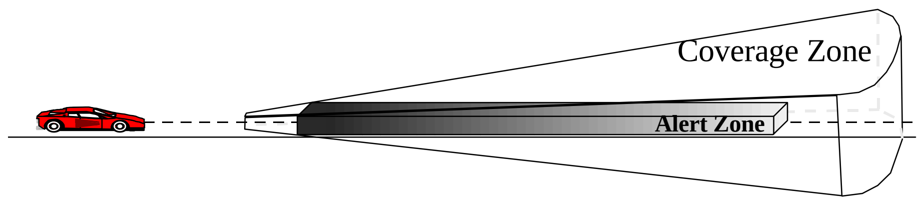


Figure 7 - Coverage and Alert Zone of an FCW System

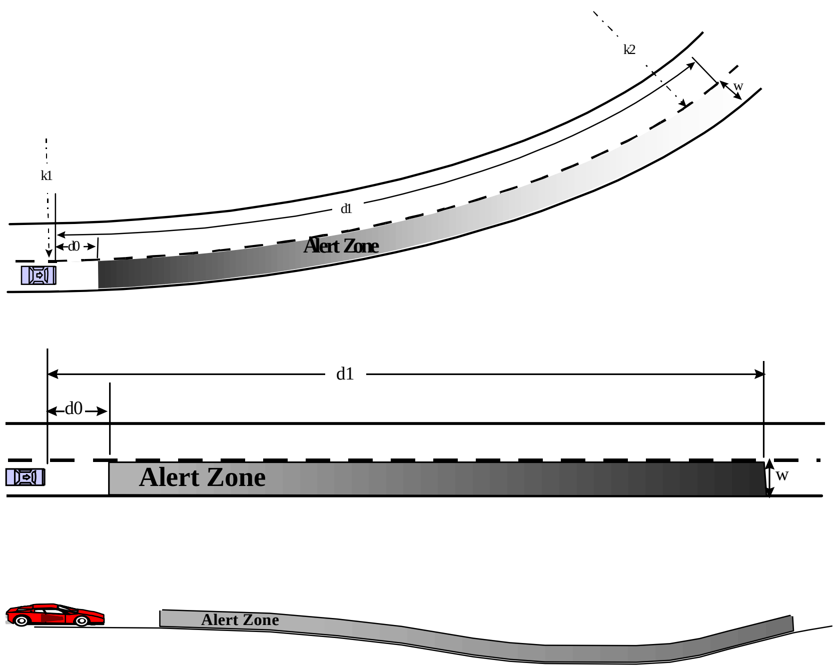


Figure 8 - Alert Zone Horizontal and Vertical Shape and Size

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.

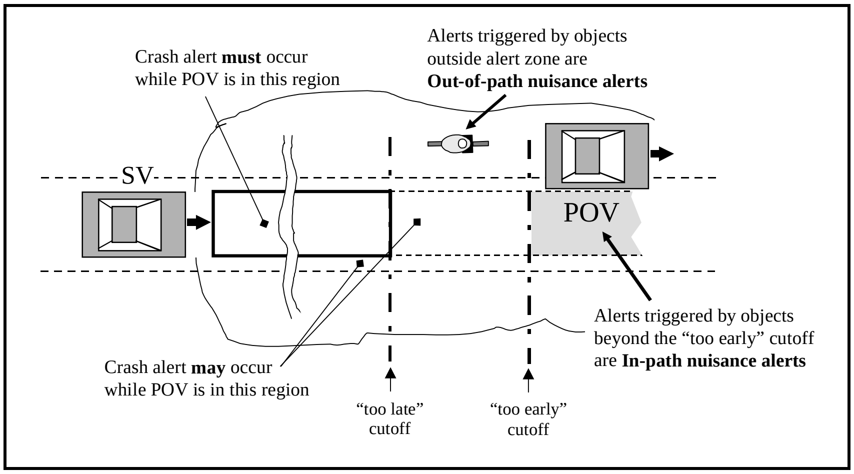


Figure 9 – Combining Alert Zone and Crash Alert Onset Timing Requirements

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

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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

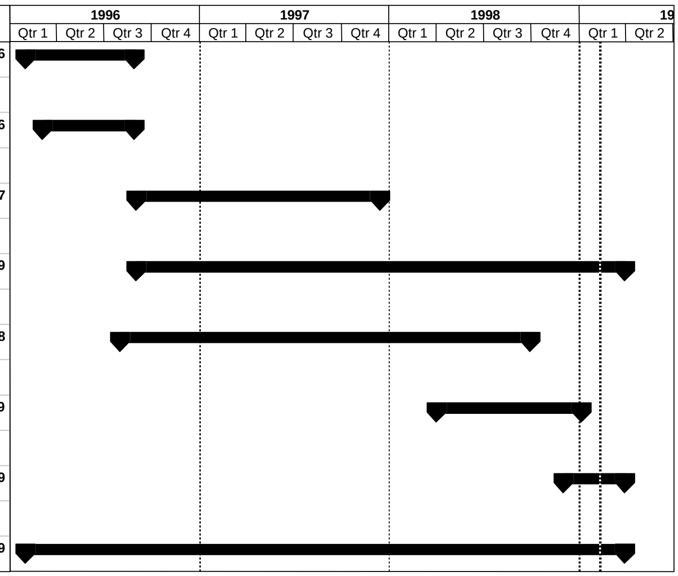

Figure 1-1 Project Tasks GANTT Chart

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

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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.

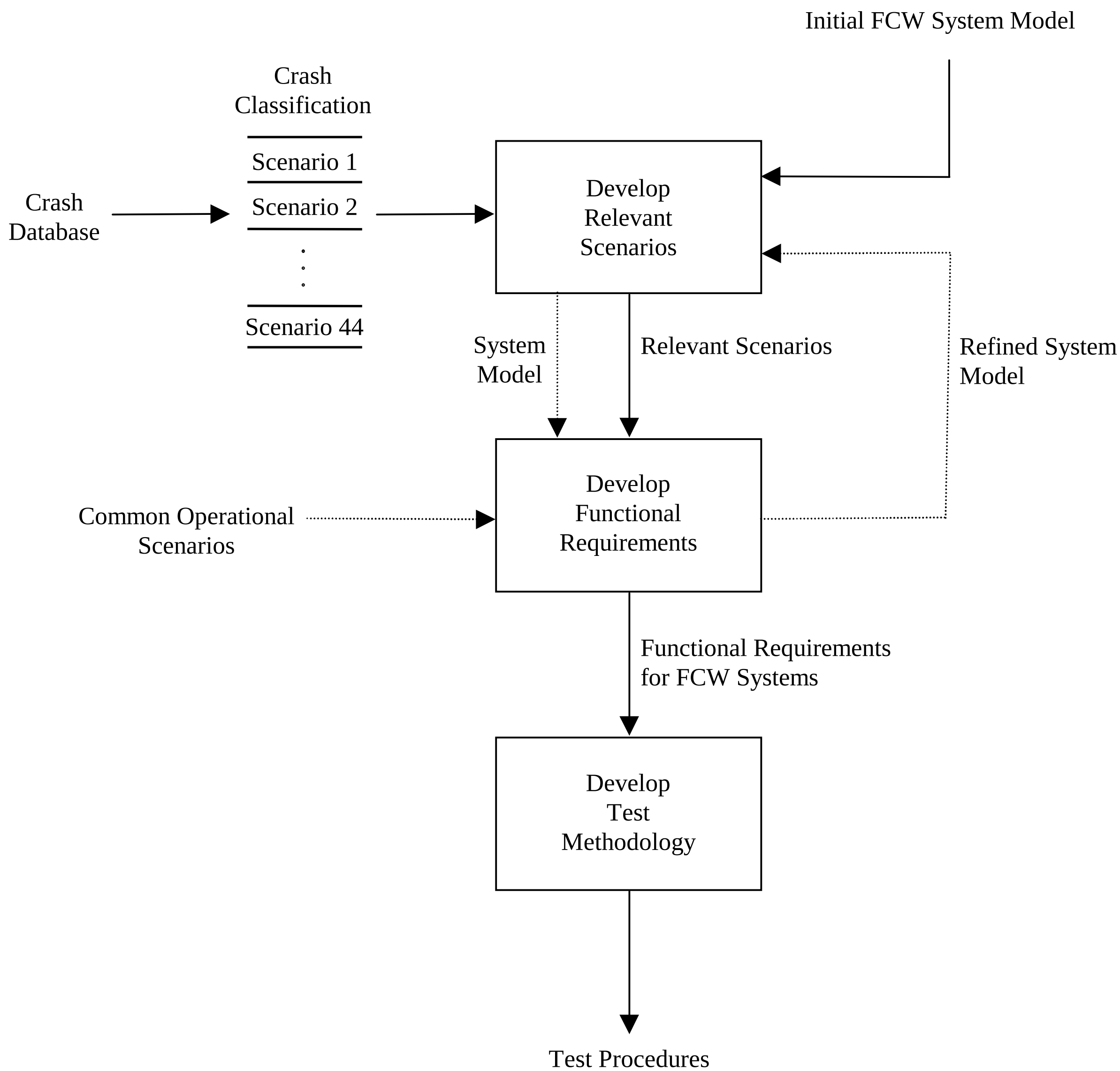

Figure 2-1 Generation and Use of Relevant Scenarios

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.

<table>
<tr><th rowspan="2"></th><th rowspan="2">No Obstacle</th><th colspan="2">In-Path Vehicle</th><th rowspan="2">Out-Of-Path Objects</th></tr>
<tr><th>Alarming Situation</th><th>Non-Alarming Situation</th></tr>
<tr><td>Alert Occurred</td><td>False alert</td><td>Appropriate alert</td><td>In-path nuisance alert</td><td>Out-of-path nuisance alert</td></tr>
<tr><td>No Alert Occurred</td><td>Appropriate non-alert</td><td>Missed alert</td><td>Appropriate non-alert</td><td>Appropriate non-alert</td></tr>
</table>

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.

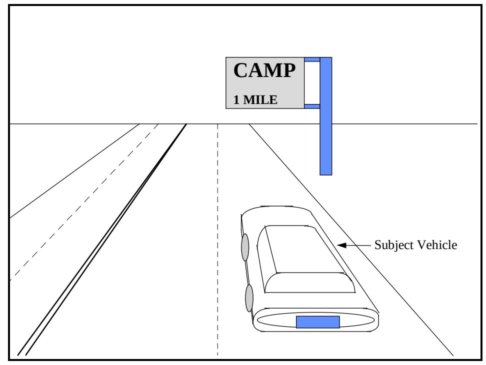

Figure 2-2 Overhead Obstacle

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.

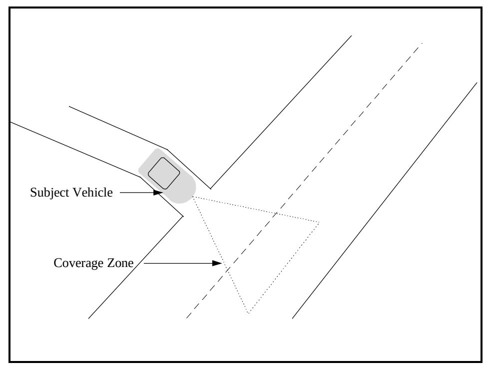

Figure 2-3 Steep Hill Scenario

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

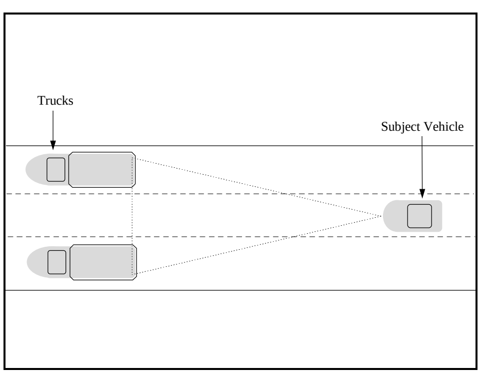

Figure 2-4 Adjacent Vehicles

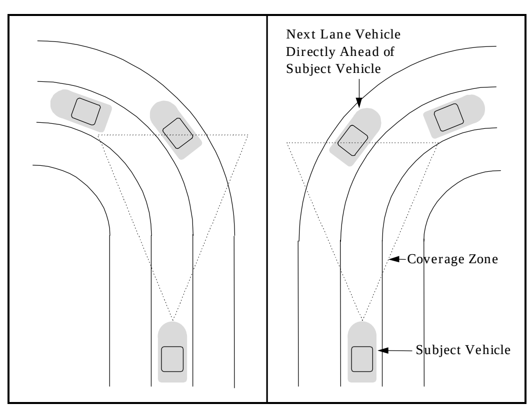

Figure 2-5 Adjacent Lane

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.

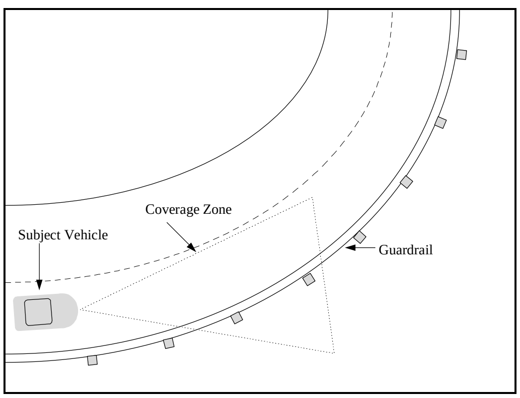

Figure 2-7 Curved Road Scenario

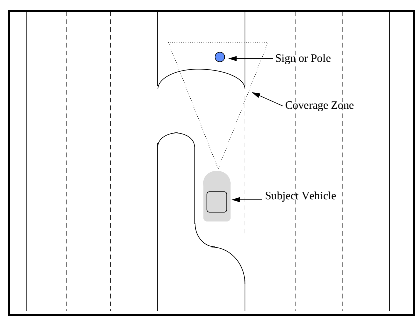

Figure 2-8 U-Turn in Median

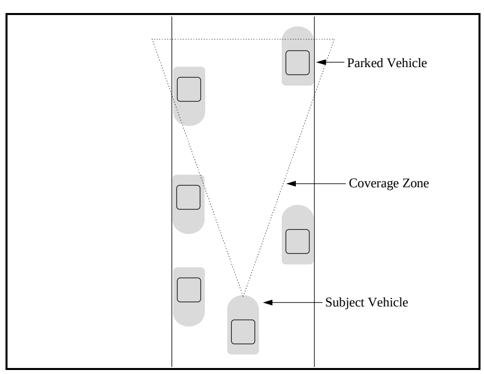

Figure 2-6 Dense Clutter Environment

2.5.5 Diverse Vehicle Sizes

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

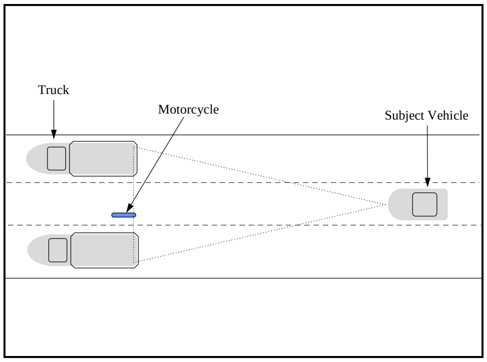

Figure 2-9 Greater Size and Equal Distance

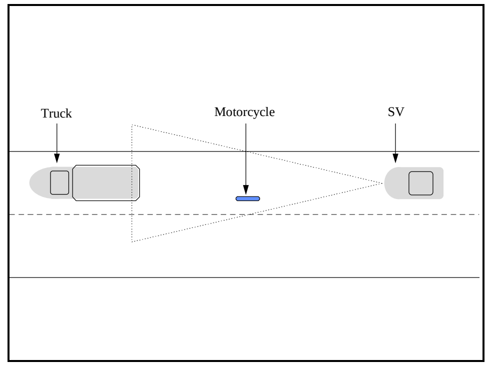

Figure 2-10 Greater Size and Distance

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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