

Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements

Foreword—This document serves as the final committee and stakeholders draft of SAE J2400 – Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements.

We note that for the sake of uniformity and international harmonization, it would be desirable for this document to be consistent with a related draft ISO standard (“Road vehicles – Forward Vehicle Collision Warning System – Performance requirements and tests procedures” ISO/TC 204/WG 14 N144.1). However, please note that differences exist between these two drafts. In part this is due to a difference in emphasis, with the ISO giving relatively more attention to details of system sensor capabilities and algorithms, and SAE J2400 putting more emphasis on the alert zone parameters and human factors considerations of the operator interface requirements. There is also a major distinction in scope, as SAE J2400 deals solely with a single-stage alert or the last stage of a multi-stage alert (sometimes referred to as an “imminent collision warning”), whereas ISO distinguishes two categories of warning – “preliminary collision warning” (i.e., non-imminent) and “collision warning” (i.e., imminent). Readers should also note that this is an “information report”, not a recommended practice or standard. Due to the lack of operational data, this first information report should be used as a starting point or reference for designers of forward collision warning systems. The authors attempted to support each of the design recommendations with supporting references. Future FCW recommended practices or standards will be based on operational data to bolster recommendations and requirements.

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- 1. Scope**—Forward Collision Warning (FCW) systems are onboard systems intended to provide alerts to assist drivers in avoiding striking the rear end of another moving or stationary motorized vehicle. This SAE Information Report describes elements for a FCW operator interface, as well as requirements and test methods for systems capable of warning drivers of rear-end collisions.

This information report applies to original equipment and aftermarket FCW systems for passenger vehicles including cars, light trucks, and vans. This report does not apply to heavy trucks. Furthermore, this document does not address integration issues associated with adaptive cruise control (ACC), and consequently, aspects of the document could be inappropriate for an ACC system integrated with a FCW system.

2. References

- 2.1 Applicable Publications**—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the latest revision of SAE publications shall apply.

2.1.1 OTHER PUBLICATIONS

- American Association of State Highway and Transportation Officials [AASHTO](2001), A policy on geometric design of highways and streets.
- Balbale and R. Kiefer (2001). Driver preference rankings of various collision avoidance related symbol. Presented at ISO TC22/SC13/WG5 (Road Vehicles-Symbols for Controls, Indicators and Telltales) meeting in Dresden, Germany.
- Gilbert, R.K., Zoratti, R., Becker, G., Brumbaugh, T., Chaplin, M., Harrison, M., and K. Gondoly (1997). Characterization and evaluation of a prototype forward-looking automotive radar: Final Report. Office of Crash Avoidance Research, National Highway Transportation Safety Administration. Washington, DC. Report No. 654100-9-F.
- ISO TC 204/WG14/N144.1. Road vehicles – Forward Vehicle Collision Warning System – Performance requirements and test procedures. [Draft only, 1999-07-19]
- Kiefer, R., LeBlanc, D., Palmer, M., Salinger, J., Deering, R., and M. Shulman (1999). Development and validation of functional definitions and evaluation procedures for collision warning/avoidance systems. DOT HS 808 964. Office of Crash Avoidance Research, National Highway Transportation Safety Administration. Washington, DC.
- LeBlanc, D., Kiefer, R., Deering, R., Shulman, M., Palmer, M., and Salinger, J. (2001). Forward collision warning: preliminary requirements for crash alert timing. Society of Automotive Engineers #2001-01-0462.
- Scolnik, M. (1970). Radar Handbook. McGraw Hill.
- U.S. Department of Transportation, Federal Highway Administration (2001). Manual on Uniform Traffic Control Devices (MUTCD).

- 3. Definitions**—For the purpose of this information report (IR), the following definitions apply. Some of these definitions have been adopted from ISO/TC204/WG14/N144, and others are specific to this SAE IR.

- 3.1 Forward Collision Warning (FCW) Systems**—Systems intended to provide alerts to assist drivers in avoiding striking the rear-end of another moving or stationary vehicle, and to help mitigate the impact of rear-end crashes.
- 3.2 Active Mode**—FCW system is receiving power and is monitoring the area ahead to detect hazards.
- 3.3 Actual Deceleration Parameter (ADP)**—The assumed deceleration of the host vehicle (expressed in g's) in response to an alert, used in computing the latest allowable FCW alert onset for a given kinematic situation.
- 3.4 Alert Zone**—The alert zone defines which vehicles in front of the subject vehicle are allowed to trigger FCW alerts. For an alert to be allowed, some portion of the target vehicle must lie within the alert zone at the onset of the alert, or be predicted to be within the alert zone at a time after the onset of the alert.

- 3.5 **a_{LV}** —Actual acceleration (neg. for braking) of the LV at the onset of an observed FCW alert.
- 3.6 **a_{SV}** —Actual acceleration (negative for braking) of the subject vehicle at the onset of an observed FCW alert.
- 3.7 **Brake System Lag**—Time interval between when the brake pedal is pressed and the vehicle begins to decelerate.
- 3.8 **Time Gap**—The time require (at current speeds) for the front bumper of the host vehicle to reach the current position of the rear bumper of the lead vehicle.
- 3.9 **Host Vehicle**—The FCW-equipped vehicle under consideration (also called subject vehicle).
- 3.10 **Imminent Collision Warning**—A warning to be given to the SV driver in situations which potentially require an immediate corrective action by the driver.
- 3.11 **Kinematic Situation**—A particular scenario involving a subject vehicle and lead vehicle, specifying values for their speeds, accelerations, and lateral and longitudinal placements at a given instant.
- 3.12 **Lead Vehicle (LV)**—A vehicle in the path of the subject vehicle which presents a potential threat of collision (also has been referred as the principal other vehicle).
- 3.13 **Non-functioning**—The status of a FCW system that has been manually turned off by the driver.
- 3.14 **Required Deceleration Parameter (RDP)**—The assumed deceleration of the host vehicle (expressed in g's) in response to an alert, used in computing both the recommended timing of an FCW alert onset and the earliest allowable FCW alert onset for a given kinematic situation.
- 3.15 **Standby Mode**—The system is receiving power, but the sensors and FCW system is not activated.
- 3.16 **Subject Vehicle (SV)**—The FCW-equipped vehicle under consideration (same as “host vehicle”).
- 3.17 **Telltale Visual Display**—A visual display which appears when and only when the **underlying** condition it signals is in effect. (For example, a “low fuel” icon.)
- 3.18 **Total Delay Time (DT)**—The assumed time interval between onset of a crash alert and the start of deceleration, comprising the driver's reaction time, and the nominal brake system lag.
- 3.19 **V_{SV}** —Actual speed of the subject vehicle at the onset of the FCW alert.
- 3.20 **V_{LV}** —Actual speed of the lead vehicle at the onset of the FCW alert.

4. *Operating Characteristics*

4.1 **System and Information Display Characteristics**

- 4.1.1 **APPLICATION OF POWER**—The vehicle shall apply power to the FCW system at engine start-up.
- 4.1.2 **ACTIVATION FOR USE**—FCW systems should be automatically shifted from the standby mode to the active mode for hazard detection when the vehicle is in forward motion above the minimum operating speed (see 4.1.3).
- 4.1.3 **MINIMUM OPERATING SPEED**—The minimum speed at which the system is active for use should be no greater than 40 kph. Manufacturers may activate their systems at lower speeds.

- 4.1.4 **MAXIMUM OPERATING SPEED**—There is no upper speed limit. The FCW system should provide an indication to the driver if its performance is limited at higher speeds.
- 4.1.5 **NON-FUNCTIONING OR SYSTEM LIMITATION INDICATION**—Drivers shall be informed by a continuous display that the system is non-functioning or is in a system limitation mode. A brief tone should accompany the onset of the failure or system limitation. System limitation conditions may include high subject vehicle speeds, obstructed or blinded sensor(s), and/or severe weather conditions.
- 4.1.6 **BUILT-IN DIAGNOSTIC TESTING**—All FCW devices shall include built-in diagnostic testing to verify that the device is capable of operating within specified performance limits. Diagnostic testing shall be performed automatically each time the ignition switch is turned on. Devices that fail shall automatically shift into a non-functioning mode and alert the driver (see 4.1.4).
- 4.1.7 **AUTOMATIC TERMINATION OF WARNINGS**—The device that triggers a warning should terminate the warning automatically once the rigging condition no longer exists or appropriate driver response (e.g., a given level of braking) is initiated.
- 4.1.8 **AUDITORY DISPLAYS**—The auditory display for imminent crash warnings shall be a distinctive, non-speech acoustic warning. The sound should be perceived by the driver to emanate from the general direction of threat (i.e., from the front of the vehicle). The alert sound tentatively recommended from Kiefer et al. (1999; pg 4-28) based on closed-course testing is a starting point (which was played out of both front speakers), but further field operational testing (incorporating real-world nuisance and false alarm types and rates) will be needed to assess driver acceptance of this sound.
- 4.1.9 **DEFAULT WARNING INTENSITY**—The warning should not startle. It is difficult to provide a recommended practice in this area. On one hand, warnings need to be heard over ambient noise (e.g., if the car windows are rolled down). On the other hand, startling drivers is not acceptable. A starting point based on the Kiefer et al. (1999) data for the warning intensity should be 75 dBA. Adjusting the sound level based on the ambient sound level should be considered. However, driver acceptance of such a strategy should be evaluated.
- 4.1.10 **ONSET AND OFFSET RATES**—The onset rate for sounds or tones used in crash avoidance warnings should be rapid enough to alert the driver but not so rapid as to induce severe startle effects. Onset rates of greater than 1 dB/msec but less than 10 dB/msec should be used.
- 4.1.11 **WARNING DURATION**—The device that triggers a warning should terminate the warning automatically once the triggering condition no longer exists. Based on driver response to the situation, other automatic and manual methods for terminating warnings may be permissible.
- 4.1.12 **INTERRUPTION OF OTHER AUDITORY DISPLAYS**—Imminent collision avoidance warnings should automatically interrupt or decrease the volume of other inputs to all speakers when warnings are displayed.
- 4.1.13 **VISUAL, AUDITORY, AND HAPTIC WARNINGS**—Visual displays shall not be used for stand-alone imminent collision warnings. Such warnings should be multi-modal. Currently, there are many unresolved issues associated with the implementation and driver behavior issues surrounding haptic alerts. Consequently, at present, a dual-modality alert is recommended which includes both a visual and auditory display.
- 4.1.14 **VISUAL DISPLAY LOCATION**—Visual warnings shall be located within a 10-degree cone of the driver's line of sight. Qualitatively, this generally implies a top-of-dashboard or head-up display location. A conventional dashboard location shall not be used for the visual warning. The rationale for this is based on the possibility that an instrument panel-based visual warning may distract the driver from the hazard ahead.

- 4.1.15 **MANUAL ADJUSTMENT OF VISUAL DISPLAY INTENSITY**—If the visual display is in the form of a telltale, intensity should not be adjustable. However, if the visual display is not a telltale, the vehicle's display brightness adjustment should be restricted such that at the dimmest setting the FCW status display remains visible and the driver can readily perceive the warning displays.
- 4.1.16 **CHARACTERISTICS OF THE VISUAL CRASH ICON**—Collision warning systems should use red. The symbol used should be the Kiefer et al. (1999) symbol (shown on the left below) or the more recent symbol developed by Balbale and Kiefer (2001) for ISO consideration (shown on the right below). The latter symbol has the advantage of being developed as part of an effort for an integrated set of visual crash avoidance-related warnings for various crash avoidance related systems. For each of these symbols, the symbol should be black and the background red. For specific characteristics of these icons see Kiefer et al. (1999) and Balbale and Kiefer (2001).

WARNING



- 4.2 **Requirements for the Occurrence of Crash Alerts**—The following sections are based largely on Kiefer et al. (1999) and LeBlanc et al. (2001). These requirements are considered preliminary and are likely to be revised based on ongoing research and experience.

- 4.2.1 **GEOMETRIC CHARACTERISTICS OF THE ALERT ZONE**—An alert zone defines which vehicles in the subject vehicle's path are allowed to trigger FCW imminent alerts. For an alert to be allowed, some portion of the target vehicle must lie within the alert zone at the onset of the alert, or be predicted to be within the alert zone at a time 1.52 seconds after the alert onset. The minimum zone width is the width of the vehicle and the maximum zone width is 3.6 meters, (a standard U.S. lane width), with the alert zone centered on the front-center line of the vehicle. The alert zone extends in front of the vehicle and should also follow the curvature of the road both vertically and horizontally. This is to apply on roads that are consistent with AASHTO guidelines for highway design, which consider speed, vertical and horizontal curvatures. AASHTO compliant roads with more than 8% of superelevation are excluded from this requirement (8% is AASHTO's upper limit for regions where significant snowfall or ice occur). FCW alerts due to objects outside of the Alert Zone, such as cars parked on the side of the road, mailboxes, lamp posts, roadside signs, guardrails, lead vehicles in adjacent lanes, overhead signs, or bridges, are not desirable and are considered "out-of-path" nuisance alerts. FCW alerts due to any part of the road surface (e.g., metal grating) are also considered out-of-path nuisance alerts.
- 4.2.2 **LONGITUDINAL CONDITIONS FOR ALERTS**—This information report only considers the final warning of a multiple-stage alert, and a single-stage alert. A single-stage crash alert is one that presents the driver a single warning. For FCW systems with multiple-stage alerts, the driver may receive warnings prior to the latest, most imminent "warning". Earlier stages are acceptable if they are shown not to degrade the effectiveness of the latest stage. Driver-adjustable alert timing is allowed, but the latest setting of the imminent alert stage must meet the requirements described below.

A crash alert timing approach is recommended, and requirements are given to determine whether the single stage alert or most imminent stage of a multiple stage alert is "too early" or "too late," as a function of range, vehicle speeds, and vehicle accelerations at the alert onset. These alert timing recommendations and requirements apply to the objective test procedures described later in this report, and are not necessarily meant to describe acceptable system behavior in other situations. This constraint is needed because: (1) the alert timing is based on the kinematic conditions of the human factors testing performed by Kiefer et al. (1999), (2) the timing is expressed here in a relatively concise manner that does not cover some special conditions, and (3) the selection of kinematic conditions in some tests are purposely chosen to require feasible performance levels of real-time estimation of preceding vehicle deceleration.

The three alert timing results (recommended, too-early, and too-late timings) are each computed using the same algorithm, with different values for the two driver-behavior parameters used for each result. The parameter sets are shown in Table 1.

TABLE 1—DRIVER RESPONSE PARAMETERS USED IN DETERMINING RECOMMENDED AND LIMITING CRASH ALERT TIMINGS.

Parameter	“Too early”	Recommended	“Too late”
Assumed reaction time	1.52 sec	1.18 sec	1.18 sec
Assumed driver acceleration	use RDP	use RDP	use ADP

The two reaction time values in the table—1.18 and 1.52 sec—are the 85th and 95th percentile (i.e., slower) reaction times observed in surprise-trial interface tests in Kiefer et al. (1999) that used the distraction technique that led to the highest upper-percentile values. This distraction technique involved drivers searching for a non-existent indicator on the instrument panel.

For the assumed driver deceleration responses in Table 1, “RDP” refers to the “required deceleration parameter.” This parameter is based on modeling experimental data to identify appropriate FCW timing, as described in Kiefer et al. (1999). The “ADP,” also from this reference, denotes the “actual deceleration parameter,” which is a regression fit over subject-vehicle speed to the 15th percentile values of actual braking performance (i.e., on the less aggressive end of performance) observed during trials in which the lead vehicle braked at -0.39 g (the test condition with the highest level of lead vehicle braking). For the test conditions described later, the ADP represents harder driver braking than does the RDP, so that alerts employing the ADP assumption would occur later in a developing scenario than would alerts employing the RDP, assuming no other difference between the alert timing. The difference in the timing resulting from use of the two models depends strongly on the kinematic conditions.

The ADP, which is used as the assumed value for the upper limit to drivers’ deceleration response, is shown below. Acceleration and deceleration are used synonymously throughout, and negative values indicate braking.

ADP: Acceleration, $\text{g's} = -0.260 - 0.00727 \times (\text{subject vehicle speed, m/sec})$

The parameters in Table 1 are derived from data considered to be the best that is currently available. These parameters will likely be adjusted as more data becomes obtainable.

- 4.2.3 COMPUTING ALERT TIMING REQUIREMENTS—To test compliance of a particular FCW system with these alert timing requirements, the range at which the FCW system’s imminent alert begins must be observed. The kinematic conditions at that moment are then used to compute the recommended and required values using the algorithm below.

The FCW-equipped vehicle is called the “subject vehicle” (SV), and the lead vehicle representing the potential collision threat is called the “lead vehicle” (LV). Let V_{SV} and V_{LV} denote the initial speeds of the SV and the LV, respectively, as shown in Figure 1.

Let a_{SV} and a_{LV} denote the accelerations of the SV and the LV, respectively, at the moment of interest. (Acceleration is negative for braking).

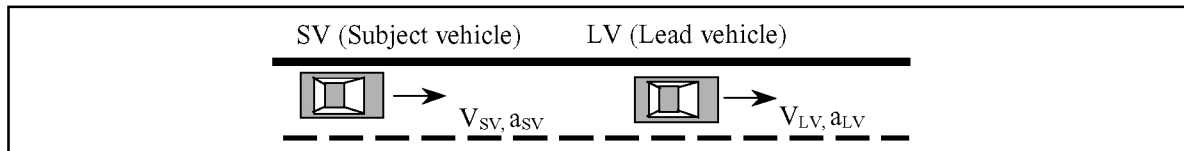


FIGURE 1—At the moment of observed alert onset

To compute crash alert timing requirements or recommendations for the objective test procedures that follow, six steps are used. These steps compute the minimum range needed between vehicles to avoid a collision, assuming (1) the lead vehicle acceleration remains constant (unless the vehicle comes to a stop, in which case it is assumed to remain stopped), and (2) the following vehicle acceleration remains constant for a delay time period, then instantaneously changes to an assumed value.

After observing the range, speeds, and accelerations of the vehicle pair at the time of alert onset, the algorithm given below will provide the ranges corresponding to alert timings that are too early, too late, or recommended (using the three sets of parameters in Table 1). Combined with the alert zone concept, the requirements can be illustrated as shown in Figure 2.

It should be stressed that this algorithm is not intended to represent a general-purpose crash alert timing algorithm, but is rather a computation of alert timing requirements or recommendations for a limited set of kinematic conditions.

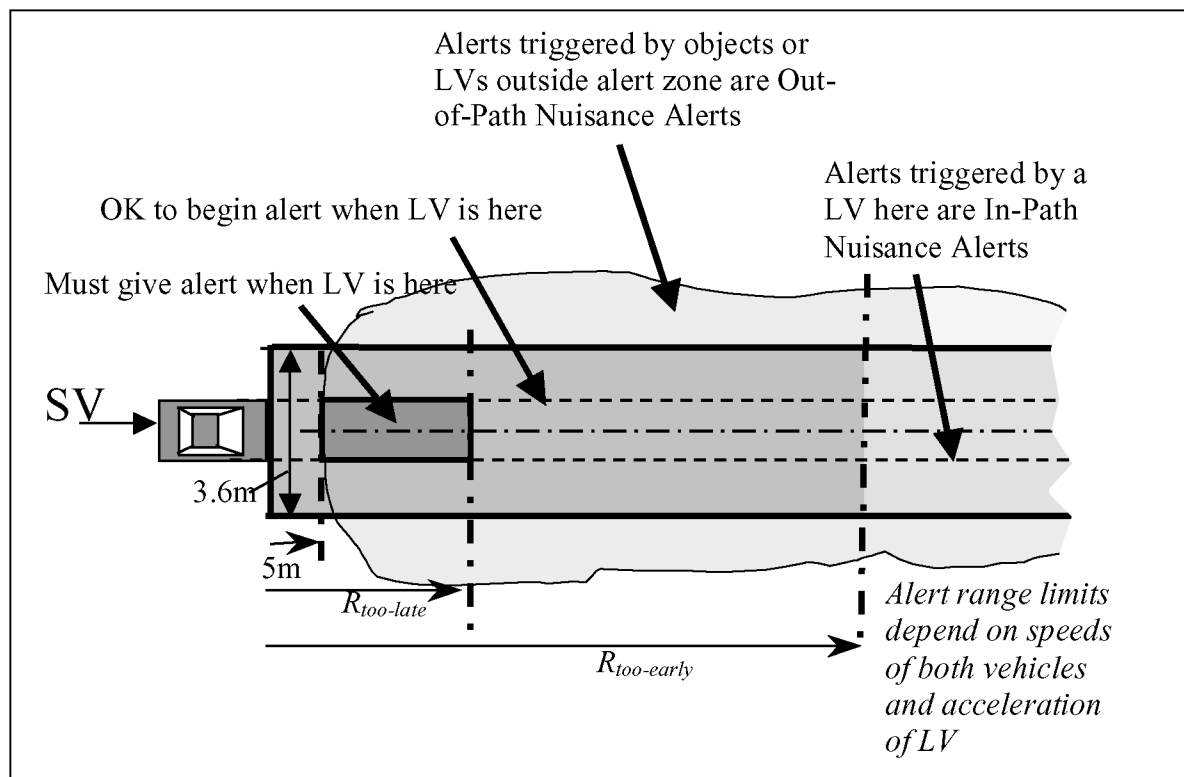


FIGURE 2—Combining alert timing rules and alert zone requirements