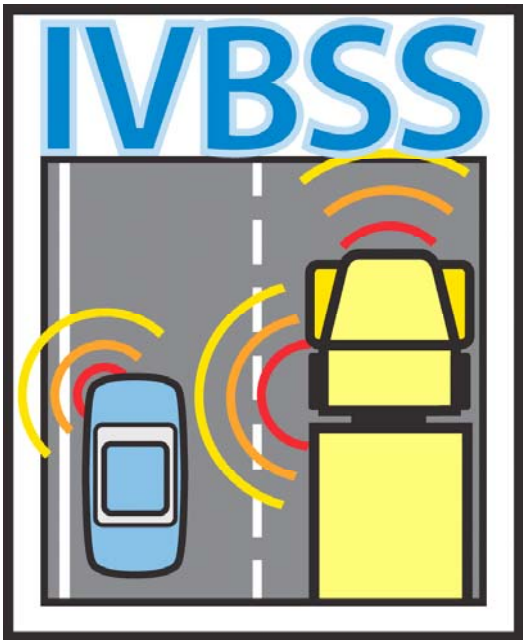

System Performance Guidelines for a Prototype Integrated Vehicle-Based Safety System (IVBSS) - Light Vehicle Platform

Prepared by

The University of Michigan Transportation Research Institute,
Visteon Corporation,
and Cognex Corporation

for the

U.S. Department of Transportation
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16. Abstract

The purpose of the Integrated Vehicle-Based Safety System (IVBSS) project is to evaluate the potential safety benefits and driver acceptance of an integrated set of crash-warning technologies installed on both light-vehicle and heavy-truck platforms. The IVBSS is an integrated set of technologies that is intended to help the driver avoid crashes by providing crash alerts in potential crash-imminent situations and advisories to enhance the driver's awareness of the driving situation.

This report proposes quantitative and measurable performance metrics that are considered achievable and appropriate for the IVBSS system on a light vehicle platform. The guidelines build upon previous project reports that present functional requirements. This effort also borrows from previous specification efforts for stand-alone crash warning systems – especially prior U.S. DOT projects and ISO standards efforts. However the focus is on the integration of these functions. In some performance areas, integration allows improvements in potential safety benefits through enhanced system awareness. In other areas, integration presents a challenge, especially in ensuring driver acceptance because the broad scope of IVBSS means more potential sources of false or nuisance alerts.

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List of Acronyms

IVBSS	Integrated Vehicle-Based Safety Systems
NHTSA	National Highway Traffic Safety Administration
SV	Subject vehicle
POV	Principal other vehicle
TTC	Time-to-collision
UMTRI	University of Michigan Transportation Research Institute
USDOT	U.S. Department of Transportation

Definitions

Advisories: Information provided by IVBSS to improve or affirm the driver's existing awareness of the surroundings. Advisories provide information for the alert and attentive driver.

Benign conditions: Daylight and clear weather, as found in the 2003 General Estimates System (GES) crash database. This does not include low-angle sun conditions.

Crash alerts: Visual, auditory, and/or haptic cues provided by IVBSS to help a driver quickly become aware of a developing hazard.

Crash alert timing: The overall result of decision algorithms that determines when crash alerts are provided.

False alerts: Crash alerts that are triggered by an inappropriate stimulus. These occur because sensor or system perception errors suggest a threat where none exists.

IVBSS: Integrated Vehicle-Based Safety System. This is the set of elements necessary to deliver the IVBSS function, which is not already part of the subject vehicle.

Lane boundary: A possibly curved line that is located along the centerline of any lane markers that delineate the subject vehicle's current travel lane from the neighboring lane or the edge of the road.

Light vehicle: Vehicles, except motorcycles, with a gross vehicle weight rating of 10,000 pounds or less.

May-inform region: A crash alert is allowed to occur when a principle-other vehicle is within the may-inform region and when alert timing and other criteria are satisfied.

Multiple-threat scenarios: Driving situations in which actions by the driver to avoid a potential collision introduce the driver to a new potential collision. For example, in order to avoid a potential rear-end collision, the driver responds by trying to change lanes, but encounters another vehicle in the adjacent lane.

Must-inform region: A crash alert is required when a principle-other vehicle is within the must-inform region and alert timing and other criteria are satisfied.

Nuisance alerts: Crash alerts given in response to an appropriate stimulus, but perceived by the driver as without value or inappropriate due to frequency, timing, modality, intensity, or the particular driving circumstances.

Outer edge: The point on the subject vehicle (excluding points on the side rearview mirror assemblies) that is farthest from the centerline of the current travel lane.

Principal-other vehicle (POV): A vehicle other than the IVBSS-equipped vehicle.

Subject vehicle (SV): A vehicle equipped with IVBSS.

System status information: Information that IVBSS provides to the driver to indicate the operational state of the IVBSS system.

Time to threshold crossing: Calculated time until the outer edge of the subject vehicle crosses a lateral-drift crash alert threshold.

1 Introduction

The purpose of the Integrated Vehicle-Based Safety System (IVBSS) project is to evaluate the potential safety benefits and driver acceptance of an integrated set of crash-warning technologies installed on both light-vehicle and heavy-truck platforms. The IVBSS is an integrated set of technologies that is intended to help the driver avoid crashes by providing crash alerts in potential crash-imminent situations and advisories to enhance the driver's awareness of the driving situation. This document presents performance guidelines for the IVBSS to be field tested on the light-vehicle platform in this project. A companion report addresses performance guidelines for the heavy-truck platform. Neither document is meant to propose guidelines or specifications for integrated crash warning systems other than the ones in this project.

This report proposes quantitative and measurable performance metrics that are considered achievable and appropriate for the IVBSS system. The guidelines build upon previous project reports that present functional requirements ([1] and [2]). This effort also borrows from previous specification efforts for stand-alone crash warning systems – especially prior U.S. DOT projects ([3], [4], {5], [6], and [7]) and ISO standards efforts ([8], [9], and [10]). However the focus here is on the ***integration*** of these functions. In some performance areas, integration allows improvements in potential safety benefits through enhanced system awareness. In other areas, integration presents a challenge, especially in ensuring driver acceptance because the broad scope of IVBSS means more potential sources of false or nuisance alerts.

This document replaces the earlier document entitled Preliminary System Performance Guidelines for a Prototype Integrated Vehicle-Based Safety System – Light Vehicle Platform. The guidelines in this document were generated by project members Visteon Corporation, Cognex Corporation, and UMTRI. This document does not necessarily represent the views or policies of the U.S. DOT.

2 Objectives of the IVBSS

2.1 Two major objectives

IVBSS should be designed to achieve two objectives:

- To help drivers avoid or reduce the harm associated with several crash types
- To earn driver acceptance of the system so that the safety benefits may be realized

2.2 Targeted crash types

IVBSS should provide information to assist drivers in avoiding or reducing the severity of the following crash types:

- Rear-end crashes in which the subject vehicle equipped with IVBSS strikes the rear-end of another vehicle (called the principal-other vehicle)
- Curve-overspeed road-departure crashes in which the subject vehicle leaves the roadway due to excessive speed in a curve
- Lateral-drift road-departure crashes in which the driver of the subject vehicle unintentionally allows the vehicle to drift off the road
- Lane-change crashes in which the subject vehicle changes lanes and collides with another vehicle moving in the same direction
- Merging crashes in which the subject vehicles merges into traffic and collides with another vehicle

The scenarios to be addressed were identified in [11].

3 Exchange of information with the driver

A central feature of IVBSS is the manner in which information will be provided to the driver. This information exchange is critical both to achieve safety benefits and to avoid annoying drivers through excessive false alerts, nuisance alerts, and annoying driver cues. This subsection presents high-level guidelines.

3.1 Three types of information

IVBSS should be designed to assist the driver in avoiding or reducing the severity of the targeted crash types by providing the driver with one or two types of information about the driving situation:

- Crash alerts (required)
- Advisories (optional)

Crash alerts were defined in [1] as information that helps the driver be aware of a potential crash conflict, so that the driver may decide whether and how to initiate an evasive maneuver. Advisories are information intended to assist the driver to reduce the likelihood that a crash conflict will develop. Unlike crash alerts, advisories are intended to improve the situation awareness of an alert and attentive driver, but do not indicate the need for the driver to act quickly.

A third type of information is system status. This allows the driver to know when the system is operating at lower levels of performance and also provides feedback regarding the driver's inputs to IVBSS made using IVBSS driver controls.

3.2 Crash alerts and advisories

Table 1 describes the crash alerts for the light-vehicle platform. Table 2 describes the advisories for the light-vehicle platform. These tables reflect the driver-vehicle interface developed for the light-vehicle IVBSS system during Phase 1 of this program; recall the IVBSS system was installed in a post-production environment.

3.2.1 Crash alerts

3.2.1.1. General crash alert qualities

Each crash alert should have either an auditory or a haptic cue, or a combination of both. Each crash alert should be accompanied by a visual indicator that allows the driver to confirm the type of alert that was received after the event has passed. Visual cues are not intended to provide a primary alert function since the intended effect of crash alerts is for unaware drivers to turn their attention to the crash risk and not be drawn to IVBSS visual cues. The visual cue should be displayed long enough to allow the driver to view the indication after the event has passed.

3.2.1.2. Crash alerts to address rear-end crash scenarios and curve-speed crash scenarios

The crash alerts used to reduce or mitigate rear-end and curve-overspeed crashes should have an audible cue. A haptic brake pulse should be used for rear-end crashes, but is optional for curve-overspeed crashes. The haptic and auditory cues given in these two types of events should be the same in order to reduce the overall number of distinct crash alert cue sets, and to acknowledge that the desired driver behavior is to consider the forward scene and make a decision about whether evasive action may be needed.

3.2.1.3. Crash alerts to address lateral crash scenarios

Lane-change merge crashes occur when the driver intentionally crosses into an occupied, same-direction adjacent lane. This conflict type is addressed by an audible cue that is provided when the driver indicates movement into an occupied adjacent lane, either by turn signal usage or as determined via vehicle dynamics.

Lateral drift crashes in which the driver unintentionally allows the vehicle to drift from the road or out of the original travel lane are addressed in two ways. First, if no object is alongside or just beyond the lane boundary, only a haptic cue is provided. Second, if an object is perceived along or just beyond the lane boundary, an audible cue is provided. This is the same audible cue that is given in situations that may lead to a lane-change or merge crash.

Table 1. Crash alerts for the light-vehicle platform prototype

Type of crash conflict	Crash alert		Crash alert visual indicator
	Auditory component	Haptic component	
Striking rear-end of vehicle ahead	Audible cue A 	Brake pulse	Text: "Hazard Ahead"
Curve-overspeed crash	Audible cue (same as above) 	Brake pulse (optional, same pulse as above)	Text: "Sharp Curve"
Drifting off road – no object identified as crash threat or Drifting out of lane– no object identified as crash threat (optional)	None	Haptic vibration in seat (directional)	Text: "Drift Left/Right"
Drifting off road or out of lane–object identified as crash threat or Lane-change crash or merging crash	Audible cue B (directional) 	None	Text: "Left/Right Hazard"

Table 2. Advisories for the light-vehicle platform

Driving circumstance	Advisories (visual only)
Following or approaching a stopped or same-direction vehicle	Forward target detected (optional)
Approaching a curve	Information regarding upcoming curve (optional)
Traveling with another same-direction (or stopped) vehicle in an adjacent lane	Indicator or icon provided when vehicle is in, or is approaching, the blind spot zone[1] (optional)

[1] See Section 5.1.1 for definition of blind-spot zone.

The issuance of a crash alert for drifting into an unoccupied, adjacent travel lane is meant to (a) improve safety benefits for lane change crashes (by reducing unsignaled lane changes), and (b) increase driver acceptance by providing consistent reinforcement that the system expects the vehicle to be kept within the lane.

The auditory and haptic cues given when the vehicle is drifting toward a perceived crash threat may be directional, so that the driver senses that the tone or seat vibration originates from the direction of the potential crash threat.

3.2.2 Advisories

All advisories are optional. All advisories should be visual cues only. Some constraints on when advisories are allowed are given in section 5.1.2.

3.2.2.1. Blind-spot zone advisory

IVBSS may include a visual cue that indicates that a same-direction, adjacent-lane vehicle is in the subject vehicle's blind spot. If the vehicle is not yet in the blind spot, but is approaching from the rear, a visual-only advisory is also allowable. The cue should be located so that a driver is likely to see the cue if they consult their side rear-view mirror.

3.2.2.2. Forward zone advisory

IVBSS may provide the driver with an indication that a forward vehicle is being tracked by the system.

3.2.2.3. Speed for upcoming curve

IVBSS may provide a visual cue that indicates that the current speed may be too great for an upcoming curve.

3.3 Managing multiple threats

3.3.1 Arbitration of alerts

When there are multiple existing or emerging potential crash threats, one alert at a time should be presented. Subsequent alerts are queued. Depending on the situation, there may be alerts that are postponed or suppressed altogether in order to promote the highest probability of safety.

3.3.2 Sequences of alerts

When multiple-threat situations arise, IVBSS may issue a sequence of crash alerts during which different types of crash alerts may occur, or one or more crash alert types occur more than once. The following should hold, however, to reduce the chances of confusing the driver in situations with true risk, or annoying the driver in situations of less risk:

- For curve-overspeed conflicts, an alert associated with that conflict which has been requested by the subsystem within 15 seconds of an earlier alert for that conflict will be ignored.

- For all other conflict types, when one alert has been issued for a specific conflict type and instance of conflict (e.g., a given lane-change merge conflict), another cannot be queued within 3 seconds of the initial alert.
- If a higher-priority alert is requested by another subsystem within 3 seconds of an initial alert, the new alert will be queued and presented to the driver immediately after the original alert is finished. Higher priority alerts are identified as follows:
    - Imminent and "lateral-direction" threats – i.e., lateral drift with a nearby crash threat, and lane-change/merge threats – have the same priority as other ongoing imminent lateral threats.
    - Imminent and "forward" threats – i.e., curve-overspeed conflicts and forward crash conflicts – have the same priority as other ongoing imminent forward threats.
    - When an initial alert has begun in response to a lateral threat, then new alerts that are imminent and longitudinal in nature (forward crash or curve-overspeed) have higher priority and may be queued.
    - When an initial alert has begun for a longitudinal threat, then new alerts that are imminent and lateral in nature (lateral drift with a nearby crash threat or lane-change/merge threats) have higher priority and may be queued.
    - Cautionary threats (e.g., lateral drift conflicts without any detected crash threats near the lane boundary) have no priority.
- Only one new alert is allowed to be queued during any 3-second period. All subsequent alerts within that time period will be disregarded.

3.4 Driver controls

3.4.1 Volume control of audible alerts

The driver should be able to adjust the volume of the audible alerts within a range that still allows auditory cues to be heard.

3.4.2 Temporary suspension of crash alerts

IVBSS may provide the driver with an ability to temporarily suppress crash alerts for no more than six minutes at a time. This acknowledges certain rare instances when the driving environment may lead to multiple unnecessary alerts (e.g., construction zones).

IVBSS should not allow a driver to completely turn off the crash alerts beyond the temporary suspension.

3.5 Automatic accommodation of driving styles

A second means of providing adjustment is through a driver assessment algorithm. Such an algorithm may determine the overall driving style of the driver, and recent driver behavior indicative of varying levels of alertness. Such an algorithm should adjust the crash alert performance by no more than 15 percent from nominal.

3.6 System status information

There may be two types of system status messages given to the driver. The first addresses the state of IVBSS and the second provides feedback regarding any selections the driver has made to adjust IVBSS performance.

3.6.1 IVBSS quality of performance

The IVBSS system may provide an indication to the driver when the IVBSS system capability is deemed to be significantly reduced.

3.6.2 IVBSS requests for driver action

IVBSS may provide an indication that the driver needs to take action to return IVBSS to its proper operating state. An example of such driver correctable faults is requesting that the driver clear a blockage on a sensor fascia.

3.6.3 Status of driver-selected features

IVBSS may provide feedback of the value of any driver-selected inputs that the system provides as described in section 3.4. This feedback may be continuous or event-driven.

4 Domain in which guidelines apply

4.1 Subject vehicle characteristics

These guidelines apply to IVBSSs installed onboard any light vehicle (see Definitions).

4.2 Target vehicle types

The guidelines that address functions related to interactions with other vehicles on the roadway should be satisfied for motor vehicles that are licensable for use on public roadways. The guidelines do not address performance related to the detection and tracking of pedestrians, pedalcyclists, animals, small motorbikes (less than 100 cc engine displacement), or non-vehicle objects.

4.3 Roadway characteristics

The guidelines in this document should apply while the IVBSS-equipped vehicle is traveling on a paved roadway managed by a public agency or while traveling on a privately-operated toll road that is open to the public.

The following guidelines address roadway geometries:

- IVBSS should detect vehicles that pose a forward collision threat, including stopped vehicles on a roadway with a radius of curvature of 500 meters or greater.
- IVBSS should estimate the position of the subject vehicle within the lane boundaries on a roadway with a radius of curvature of 125 meters or greater.
- IVBSS should identify roadway radius of curvature when the radius is 75 meters or greater.
- IVBSS should detect vehicles in the adjacent lane on a roadway with radius of curvature of 250 meters or greater.
- IVBSS should operate on roadway segments where the roadway crests with a negative vertical curvature that does not exceed that in the AASHTO design guidelines [12].

4.4 Operating speeds

The guidelines herein should be satisfied for operating speeds between 11.4 m/s (25 mph) and 26.8 m/s (60 mph). IVBSS should operate at speeds up to, or exceeding, the posted speed limit but above 26.8 m/s, IVBSS is not required to meet all performance guidelines in this document. This allowance is necessary because of limits with current remote sensing capabilities.

4.5 Availability requirements

IVBSS should be available to provide crash alerts at least 90 percent of the travel time under benign conditions. Benign conditions prevail during the vast majority of crashes according to a recent Volpe study [11]. The exception is that IVBSS should be available to provide crash alerts associated with lateral drifting events at least 50 percent of travel time on surface streets.

The IVBSS lane boundary tracking should be successful on both lane boundaries at least 75 percent of the travel time under nighttime conditions that are otherwise benign.

5 Occurrence of crash alerts

5.1 Conflicts that generate crash alerts

5.1.1 Alert zones

To alert the driver of potential crashes with other vehicles, IVBSS should be capable of providing alerts for vehicles located in a contiguous area around the subject vehicle (SV) that is comprised of four zones: forward, adjacent forward, blind spot, and adjacent rear. Each of these zones in turn is comprised of must-inform and may-inform regions. Figure 1 shows the forward zone and Figure 2 shows the adjacent forward, blind spot, and adjacent rear zones. These zones all follow the horizontal and vertical curvature of the lane in which the SV is traveling, although they are shown for straight roads in the figures. Details of the dimensions of the forward zone are given in both figures.

Furthermore, to alert the driver of potential unintended lane or road departures, IVBSS should be capable of providing alerts when the SV moves into the may-inform or must-inform regions shown in Figure 3 for lateral drift scenarios. These zones and regions also follow the lane curvature. Figure 3 is a revised form of the figure used in the ISO standard on lane departure warning systems [8]. More detailed descriptions and meanings of these three figures are provided in the next section.

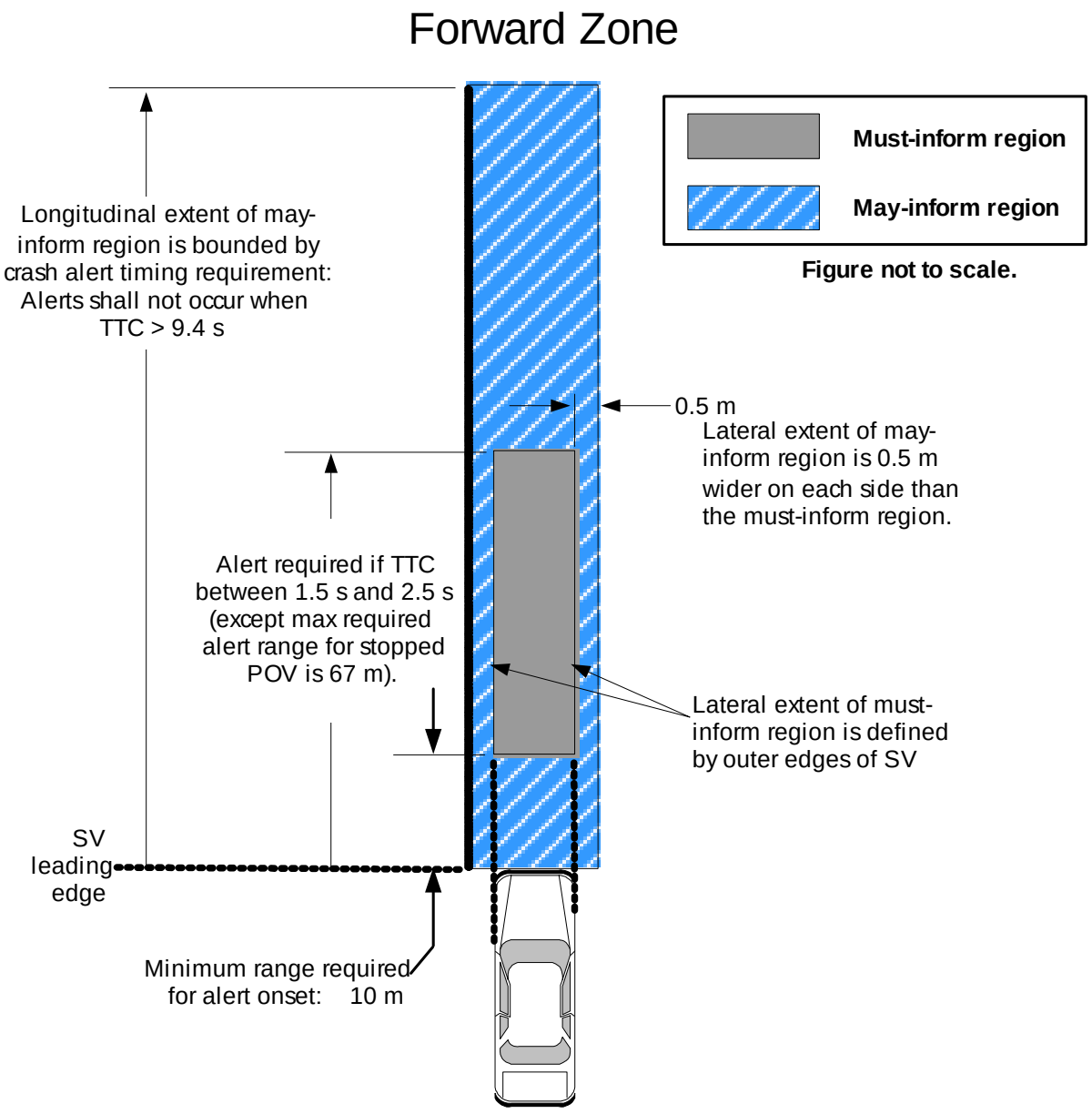

Figure 1. IVBSS light-vehicle forward zone for addressing rear-end crashes

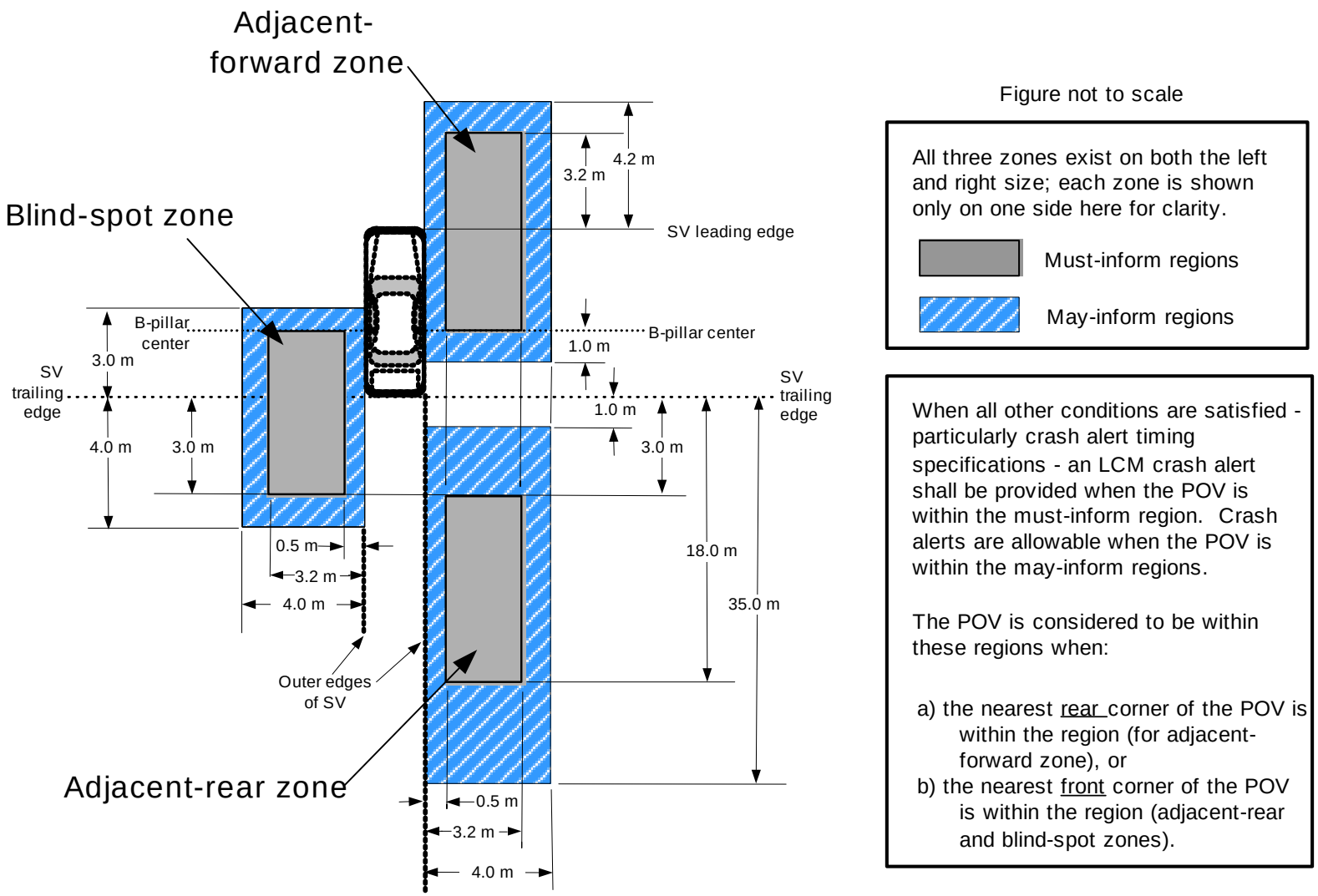

Figure 2. IVBSS light-vehicle zones for addressing lane-change merge crash types

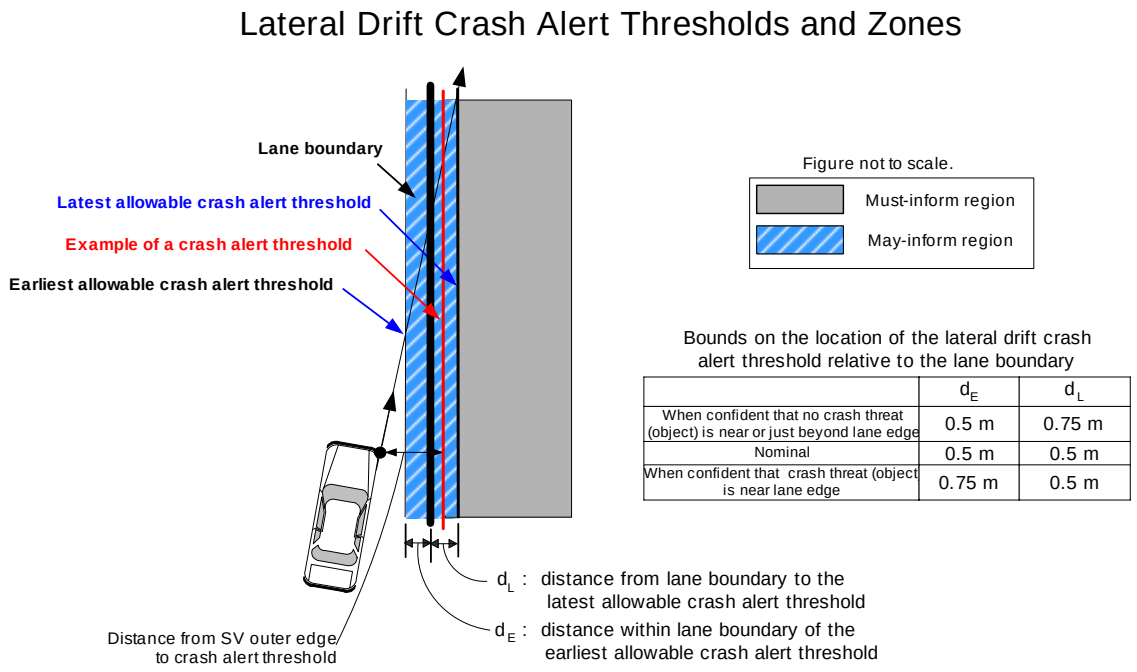

Figure 3. IVBSS light-vehicle crash alert zones and thresholds addressing lateral-drift crashes

5.1.2 Crash alert timing and issuance of advisories

When IVBSS has confidence in its information and all other conditions are satisfied, it:

- Should issue crash alerts in the must-alert regions, when alert timing criteria (below) are satisfied
- Is allowed to issue crash alerts in the may-alert regions, when alert timing criteria (below) are satisfied
- Should not issue crash alerts outside these regions.

The detailed guidelines for crash alert timing in each zone differ, based on the nature of the threats in each zone and the maneuvering required by the SV to avoid or mitigate a crash.

Sections follow that address crash alert timing in the zones of Figures 1, 2, and 3. Subsequent to those sections are allowances for advancement, delay, or suppression of alerts based on information available to IVBSS.

5.1.2.1. Forward-zone crash alerts and advisories

5.1.2.1.1. Forward zone lateral extent

The forward zone shown in Figure 1 is a 2.8-meter wide corridor, measured from the front center of the subject vehicle.

The width of the must-alert region in the forward zone is equal to the width of the SV, and is aligned with the outer edges of the SV. The width of the may-alert region is confined to the present travel lane. While changing lanes, the lateral location of the forward zone is not defined for the purposes of this guideline.

5.1.2.1.2. Forward zone longitudinal extent (alert timing)

Crash alerts should occur when the time to collision, as computed using range, vehicle speeds, and lead vehicle deceleration, is between 1.5 and 2.5 s. Crash alerts may occur when the time to collision is between 2.5 and 9.4 s. he crash alert, however, shall not occur if the time to collision is greater than 9.4 seconds.

Crash alerts are allowed but not required when the time to collision is less than 1.5 s. Furthermore, the minimum range at which an alert is required is 10 meters. These guidelines acknowledge occasionally difficult circumstances in which other vehicles cut in front of the subject vehicle, or in which forward conflicts develop quickly at short range. The efficacy and benefits of alerts in circumstances in which crash alerts can be provided only at short distances or time to collisions may be less than crash alerts provided in other circumstances.

The maximum required range at which an alert is required may be computed from previous guidelines, except that if the object is stopped and has never been observed to move, the maximum range at which a crash alert is required is 67 meters. This is equivalent to a time to collision of 2.5 s in the case of the subject vehicle approaching a stopped vehicle at 26.8 m/s (60 mph).

Advisories are allowed for the detection or the presence of vehicles in the forward alert zone, or in portions of the forward zone, including both the must-inform and may-inform regions of the forward zone. The advisory should be given any time a confirmed target is less than 100 meters ahead of the subject vehicle.

5.1.2.2. Crash alerts and advisories for vehicles in the blind-spot zone, adjacent-rear zone, or adjacent-forward zone

Figure 2 showed the alert zones for lane-change/merge crash scenarios. When an SV is changing lanes or merging into another lane and at least one principle-other vehicle (POV) is within the blind spot, adjacent-rear, or adjacent–forward zone, the following should hold:

- A crash alert should occur no later than when the time to collision (as defined by distance divided by closing speed) becomes less than 1.1 seconds. For the rear-adjacent zone, the crash alert should occur no later than when the time to reach the blind zone (as defined by longitudinal distance behind the may-inform region of the blind zone divided by the longitudinal closing speed of the POV) is less than 1.1 seconds. (See also later allowances for delaying or suppressing alerts based on subject vehicle position within the lane or lack of motion toward the adjacent lane.)

- A crash alert should not occur if the time to collision (range divided by closing speed) exceeds 7.0 seconds. When the POV is within the rear-adjacent zone and is not yet in the blind-spot zone, the crash alert cannot occur if the predicted time before the POV enters the blind-spot may-inform region exceeds 7.0 seconds.

If advisories are used, they may be provided when a same-direction vehicle is within any one of the must-inform or may-inform regions associated with the three zones addressed in this section. The logic to display or suppress advisories is likely to be complex in order to reduce nuisance and provide an intuitive function; the logic is likely to use considerations such as whether the adjacent-lane vehicle is being passed or is passing the SV.

5.1.2.3. Curve-speed crash alerts and advisories

The crash alert is intended to alert the driver if the current speed would lead to a lateral acceleration in the upcoming curve of 0.35 g or more. A crash alert should occur if the driver, in order to reduce the lateral acceleration, would need to apply 0.3 g or more of constant deceleration, beginning at a time 1.5 seconds or later after the alert.

The crash alert should not occur if a braking response 1.5 seconds after the alert requires no more than 0.07g deceleration by the SV to reduce speed to a level that produces no more than 0.25 g lateral acceleration in the curve.

Advisories are allowed in order to support the driver's awareness of the potential risk of traveling too fast into an upcoming curve. If provided, the onset of an advisory should not occur more than 10 seconds before the crash alert would occur (assuming the SV speed remains constant).

5.1.2.4. Lateral-drift crash alerts and advisories

The guideline defines a line – the lateral-drift threshold line – that is parallel to the lane boundary (see Figure 3), such that it curves with the lane boundary. The time to line crossing is defined as the predicted time until the outer edge of the SV (see Definitions) crosses the lateral-drift threshold line. This philosophy is similar to that of [8]. The simplest definition of time to line crossing assumes the drift rate is constant:

Time to line crossing =

-1 x (distance between the SV outer edge and the crash alert threshold line) / (rate of change of that distance)

IVBSS should issue crash alerts at a consistent time to line crossing. Furthermore, in most conditions, the crash alert should occur no later than when the outer edge of the SV crosses into the must-inform region of Figure 3, or equivalently, no more than 0.5 meters outside the lane boundary. In most conditions, a crash alert should not occur when the outer edge of the SV is not yet in the may-inform region of Figure 3, or equivalently, still more than 0.5 meters within the lane.

Within the may-inform zone, crash alerts may be modulated to occur at different locations based on such factors as the OEM-selected factory default, driver-selected timing preference, adaptation to driving style and environmental conditions, lateral velocity, adjacent lane or shoulder occupancy, and direction of adjacent travel lane.

Advisories may be provided for the purpose of informing the driver of lane-keeping performance only if the advisories are meant to address driver state issues, such as distraction or drowsiness.

5.2 Allowances for advancing, delaying, or suppressing alerts

In many circumstances, it is necessary to make allowances for deviations from the above in order to serve safety and driver acceptance purposes. These exceptions allow for system behavior that better matches the driver's perception of risk and hence the suitability of the crash alerts. Furthermore, it allows the system behavior to be more consistent and predictable using existing and emerging technologies.

5.2.1 Allowances for indications of awareness or intent to maneuver

IVBSS may delay or suppress crash alerts based on measured information that indicates a significant possibility that one or more of the following is true:

- The driver is aware of the perceived conflict.
- The driver intends to initiate a maneuver, or is maneuvering, such that the potential conflict could be resolved through the maneuver.

5.2.2 Allowances to advance or delay crash alerts during lateral drifting

IVBSS may provide earlier crash alerts for unintended lane or road departures if there is a perceived object at, or beyond, the lane boundary that may constitute a crash threat. These alerts, however, should not occur until the outer edge of the SV is less than or equal to 0.75 meters from the lane boundary.

IVBSS may delay crash alerts associated with unintended lane or road departures if there is sensing of objects beyond the lane boundary and there is no perceived object beyond the lateral drift threshold line. These alerts should occur before the outer edge of the SV is 0.75 meters beyond the lane boundary.

5.2.3 Allowances to prevent excessive false alerts

The occurrence of false alerts[2] has been a major issue affecting driver acceptance in previous U.S. DOT field operational tests ([5] and [6]). Thus the following guidelines should be met:

[2] See the Definitions section

IVBSS should issue no more than 15 false alerts per 100 miles of travel. This should apply to a representative set of driving patterns and travel on roadways and with traffic and weather conditions that are representative of U.S. travel patterns and conditions.

5.2.4 False alert and nuisance alert management

While previous field operational tests suggest that IVBSS crash alerts and advisories can be expected to reduce certain conflicts, the occurrence of these conflicts is largely beyond the control of IVBSS and depends on the driver's behavior and the traffic and roadway environment. Some guidelines have addressed the allowance of driver-adjustable settings and controls that may serve this purpose. To meet the guidelines above, however, adaptive modification of crash alert timing or suppression of crash alerts is required, as described below.

5.2.4.1. Condition-based alert management

IVBSS is allowed to suppress crash alerts for certain crash types during environmental conditions that are known to lead to excessive false alerts for certain crash types. Examples of conditions associated with poor performance of certain sensors include rainy nighttime driving, travel on minor neighborhood roads or in construction zones, travel in environments where GPS is unavailable, and heavy precipitation.

5.2.4.2. Location-based alert management

IVBSS is allowed to adjust the timing of crash alerts and suppress crash alerts based on the physical location of the SV if there is likelihood that false alerts would be introduced. An example technique is the delaying of crash alerts at a location where previously-issued crash alerts were not followed with a driver's evasive action.

5.2.4.3. Rate-based alert management

IVBSS is allowed to delay the timing of crash alerts or suppress crash alerts if several crash alerts have been issued recently and the driver has not consistently taken corrective actions.

5.2.4.4. Exposure-based alert management

IVBSS may also incorporate adjustments to the alert timing based on driving patterns monitored and modeled by the system as described in section 3.5.

6 Summary

This document presented the performance guidelines for the light-vehicle platform of the IVBSS project. These guidelines served to guide design, development, and verification specifications for the prototypes to be fielded in this project.

The guidelines in this document address many key features of the system, which may be grouped into the following topics: how to present crash warning information to the driver; the domain of operating conditions in which the information is presented; the conditions in which alerts are required, allowed, and prohibited; and allowable means of suppressing or delaying crash alerts to minimize false or nuisance alerts and maintain a system that drivers find credible and predictable. For convenient reference, selected highlights from this document have been summarized in a set of tables below and within the body of the document:

- Types of crash alerts and advisories, with driver display modalities (Tables 1 and 2)
- Alert zone definitions (Figures 1, 2, and 3)
- The domain of applicability for the guidelines as well as guidelines for availability (Table 4)
- Driver controls and system status messages (Table 5)
- Crash alert timing guidelines (Table 6)
- Conditions for advisories (Table 7)
- Maximum crash alert rates (Table 8)

These guidelines have formed part of the engineering development process that culminated in a set of testing activities that demonstrated that the prototype vehicles address key crash scenarios and do not provide excessive false alerts.

Table 3. Selected highlights addressing the domain of applicability and guidelines on crash alert availability

Highlighted item	Performance guideline
SV speeds at which guidelines should hold	25 to 60 mph (11.4 to 26.8 m/s)
Minimum curve radii for which guidelines addressing the four crash types should hold	Rear-end crash scenarios: 500 meters Lateral drift road departure crash scenarios: 125 meters Curve-overspeed road departure crash scenarios: 75 meters Lane-change/merge crash scenarios: 250 meters
Vertical curvatures for which guidelines should hold	Equivalent to AASHTO design guidelines
Availability to provide crash alerts (percent of travel time in benign environmental and roadway conditions)	Minimum 90 percent availability required, except the availability to address lateral drifting may be less at nighttime (75 percent required) and on surface roads (50 percent required).

Table 4. Selected highlights addressing driver controls and system status messages

Highlighted item	Performance guidelines
Driver control settings for auditory alert volume (optional)	The IVBSS should not allow the driver to make the auditory alerts inaudible.
Driver control for temporary suppression of all crash alerts and advisories (optional)	IVBSS may allow driver-activated temporary suppression of alerts for no more than six minutes.
System status messages	The driver may be informed when IVBSS performance is significantly reduced (including unavailable states). (Optional) IVBSS may ask the driver to take actions that will help recover full IVBSS capability (e.g., removing dirt that obstructs key sensors). The driver may receive feedback about the setting of selections for any driver controls that are present.

Table 5. Selected highlights of crash alert timing guidelines

Crash threat	Earliest crash alert allowed	Latest crash alert allowed
Closing on a POV in the forward zone	Time to collision (TTC) = 9.4 seconds	Crash alert required when TTC between 1.5 and 2.5 seconds, and allowed when TTC is less than 1.5 seconds. Max required alert range is 67 meters for stopped vehicles.
Lane-change/merge with POV in adjacent-forward and blind-spot zones	TTC = 7.0 seconds No alert if lateral distance to POV is 4 meters or more.	TTC = 1.1 seconds
Lane-change/merge with POV in rear-adjacent zone	TTC = 7.0 seconds No alert if lateral distance to POV is 4 meters or more.	Time to blind-spot zone = 1.1 seconds
Approaching a curve quickly	No alert if 0.07g or less of braking applied at 1.5 seconds after alert would lead to less than 0.25g.lateral acceleration in the curve.	Must alert if 0.3 g braking applied 1.5 seconds after alert would lead to 0.35 g or more lateral acceleration in the curve.
Lateral drift off the road or out of lane	0.5 meter within the lane (0.75 meter within the lane if POV/object is at or beyond lane edge)	0.5 meter beyond the lane (0.75 meter beyond the edge or object near lane edge if there is no POV/object beyond lane edge)

Table 6. Conditions for optional visual-only advisories

Advisory	Guidelines constraining display of advisories
Forward zone POV being tracked	Only at ranges less than 100 meters
Information about upcoming curve	Only within 10 seconds of CSW alert
Advisory of adjacent-lane POV	POV must be in the may-inform or must-inform region of the blind-spot zone, adjacent-rear zone, or adjacent-forward zone.

Table 7. Maximum nuisance alert rates

Highlighted item	Performance guidelines
Maximum false and nuisance alert rate (average rate when sampling representative driving patterns and environments)	15 alerts per 100 miles

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