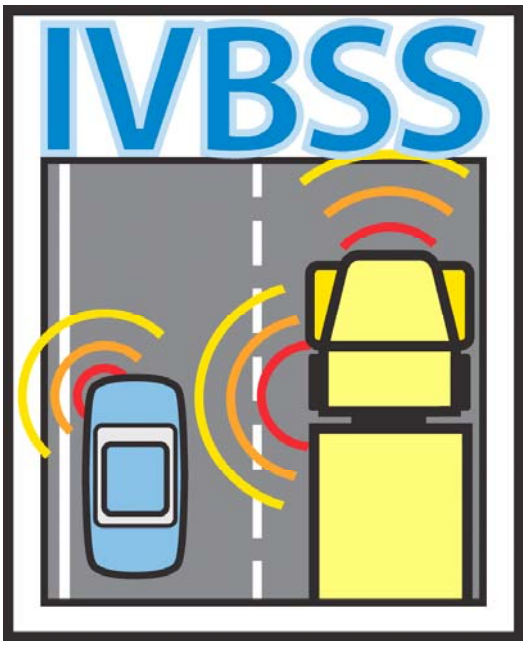

System Performance Guidelines for a Prototype Integrated Vehicle-Based Safety System (IVBSS) - Heavy Truck Platform

Prepared by

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

for the

U.S. Department of Transportation
under Cooperative Agreement DTNH22-05-H-01232

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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 heavy truck (Class 8). 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
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.

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

Crash alerts: Visual, and/or auditory 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.

Heavy truck: Class 8 trucks with a gross vehicle weight rating exceeding 33,000 pounds.

IVBSS (Integrated Vehicle-Based Safety System): 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 along the lane marker centerline that delineates the subject vehicle's travel lane from the adjacent lane or the road edge.

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 alert timing and other criteria are satisfied.

Multiple-threat scenarios: Driving situations in which driver evasive action introduces a new potential collision.

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.

Status information: Information that informs the driver of IVBSS operational state.

Time headway: The distance from the subject vehicle to a preceding vehicle, divided by the subject vehicle speed.

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 imminent crash 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 heavy-truck platform in this project. A companion report addresses performance guidelines for the light-vehicle platform. Neither document is meant to propose or prescribe 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 projects sponsored by the United States Department of Transportation (U.S. DOT) ([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 – Heavy-Truck Platform. The guidelines in this document were generated by project members Eaton Corporation, Cognex Corporation, and the University of Michigan Transportation Research Institute (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 shall be designed to achieve two objectives:

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

2.2 Targeted crash types

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

- Rear-end crashes in which the subject vehicle strikes the rear-end of another vehicle
- 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 in an adjacent lane moving in the same direction
- Merging crashes in which the subject vehicles merges into traffic and collides with another vehicle

The crash 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 display 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 shall 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 (required for rear-end and lane change crash types, optional for other types)

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.

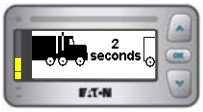
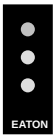
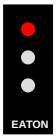
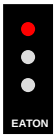
Advisories are information displays intended to assist the driver to reduce the likelihood that a crash conflict will develop. Unlike crash alerts, advisories are intended to improve the situation awareness of an alert and attentive driver, but do not indicate the need for the driver to act quickly.

A third type of information is system status. System status information informs the driver when the system is operating at lower levels of performance, and also provides feedback to the driver when the driver makes inputs to IVBSS using IVBSS driver controls.

3.2 Display modalities for crash alerts and advisories

Table 1 shows the display modalities for the different targeted crash types and the required cues. This table reflects the driver-vehicle interface developed for the heavy-truck IVBSS system during Phase 1 of the program. Ongoing human factors experiments may result in revisions that would modify the exact audible cues implemented for the Phase 2 field operational test vehicles.

Table 1. Crash alerts and advisory displays for the heavy-truck platform

Type of crash conflict	Crash alert auditory display	Crash alert visual indicator	Advisories only
Striking rear-end of vehicle ahead	Audible cue set A (non-directional) 		Forward target detected, time headway warnings 
Drifting off road (and optionally out of lane) – no object identified as crash threat	Audible cue B (directional) 		n/a 
Drifting off road or out of lane – object identified as crash threat	Audible cue C (directional) 		Indicator for adjacent lane vehicles 
Lane-change crash or merging crash	Audible cue C (directional) 		Indicator for adjacent lane vehicles 

3.2.1 Crash alert displays

3.2.1.1. General display qualities

Each crash alert shall have an auditory cue. Each crash alert shall 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 shall 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

The crash alerts used to reduce or mitigate rear-end crashes shall have a non-directional audible cue. The auditory cues given for rear-end crash types shall be distinct from other audible crash type cue sets 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-drift crash scenarios including lane-change/merge

Road-departure crashes in which the driver unintentionally allows the vehicle to drift from the road are addressed with two distinct audible cues. First, if no object is alongside or just beyond the lane boundary, an audible cue is provided. Second, if an object is perceived along or just beyond the lane boundary, a more prominent audible cue is provided. This second cue is the same as that given in situations that may lead to a lane-change or merge crash.

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

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

3.2.2 Advisory displays

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.

3.2.2.2. Advisories to address rear-end crash scenarios

Different from the light-vehicle platform, advisories addressing rear-end crash scenarios are *required* for the heavy-truck platform. This difference is primarily due to the reduced braking

capabilities of a heavy truck as compared to a light vehicle, so that an important component of crash avoidance is the use of safe headway distances. The advisories shall be both auditory and visual cues based on time headway. Time headway is the time required by the subject vehicle to travel forward and reach the forward vehicle's *current* location. The heavy-truck system may also provide the driver with a visual indication that a forward vehicle is being tracked by the system.

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 shall be presented. However, preemption of alerts may be implemented. Depending on the situation, there may be alerts that are postponed or suppressed altogether in order to promote the highest probability of safety. (These guidelines are being re-examined and should be considered in this light.)

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 minimum time allowed between consecutive crash alerts of the same type and severity is 3 seconds. For concurrent crash alerts of different types or severities, the arbitration logic shall allow a higher priority alert to preempt a lower priority alert.

3.4 Controls for the driver and/or fleet manager

3.4.1 Accommodating differences in drivers

IVBSS shall accommodate differences in driving style, individual fleet needs, and the elements of the driving environment that promote conflicts, and still earn acceptance by fleet managers and drivers.

3.4.1.1. Volume control of audible alerts

The fleet manager and (if the fleet wishes) the driver shall be able to adjust the volume of the audible alerts within a range that still allows auditory cues to be heard.

3.4.1.2. Temporary suspension of crash alerts

IVBSS is allowed to provide the driver with an ability to temporarily suppress crash alert displays for no more than six minutes at a time and no more than two minutes per driver command. This acknowledges certain rare instances when the driving environment may lead to

multiple unnecessary alerts (e.g., construction zones). IVBSS shall not allow a driver to completely turn off the crash alerts beyond the temporary suspension.

3.4.2 Preference control for alert timing

IVBSS may allow the fleet manager to set a preference for the timing of crash alerts (sooner versus. later). If this setting is provided, there shall be two preference switches: one to jointly adjust the lateral-drift and lane-change/merge alerts and one to adjust alerts addressing rear-end crashes. The guidelines in this document shall be satisfied at any setting.

Allowances are made in later sections for automatically adapting alert timing based on observations of recent occurrences of conflict or driving performance, as well as adjustments for changes in estimates of driver state.

3.5 System status information

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

3.5.1 IVBSS quality of performance

IVBSS must provide an indication to the driver when the system cannot perform at the levels stipulated in these performance guidelines. This includes availability to provide crash alerts, as well as subtler performance degradations such as reduced sensing range in difficult conditions.

3.5.2 IVBSS requests for driver action

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

3.5.3 Status of driver-selected features

IVBSS must provide feedback of the value of any driver-selected inputs that the system provides. This feedback may be continuous or event-driven. Examples of such inputs may include auditory alert levels and temporary suppression of alerts.

4 Domain in which guidelines apply

4.1 Subject vehicle characteristics

These guidelines apply to IVBSS installed onboard any heavy truck (see Definitions).

4.2 Target vehicle types

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

4.3 Roadway characteristics

The guidelines in this document shall 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 shall 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 shall 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 shall detect vehicles that pose a lane change/merge threat to the subject vehicle on a roadway with radius of curvature of 250 meters or greater.
- IVBSS shall operate on roadway segments where the roadway crests with a negative vertical curvature that does not exceed that in the AASHO highway design guidelines [12].

4.4 Operating speeds

The guidelines herein shall be satisfied for operating speeds between 11.4 m/s (25 mph) and 30 m/s (67 mph).

4.5 Availability requirements

IVBSS shall 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 recent Volpe study [11]. The exception is that IVBSS shall 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 shall be available 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 shall be capable of providing alerts for vehicles located in alert zones located relative to the subject vehicle (SV). Each zone is comprised of a must-inform zone and a may-inform zone, as illustrated in Figures 1, 2, and 3. These zones follow the horizontal and vertical curvature of the lane in which the SV is traveling, although they are shown for a straight road in the figures. Details of the dimensions of the zones and regions are given in the figures, with more detailed descriptions of their meaning in the sections that follow.

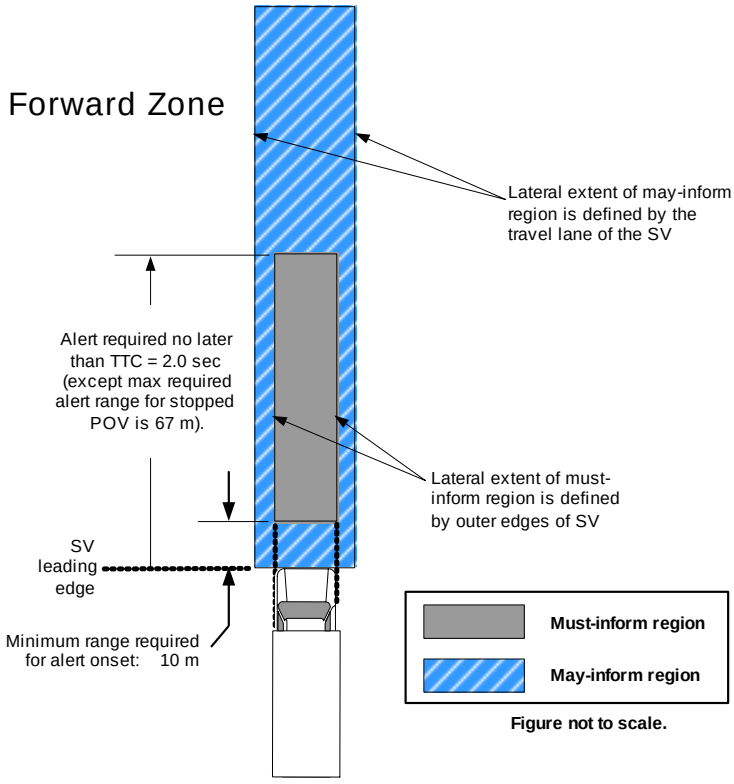


Figure 1. IVBSS forward and adjacent lane zones

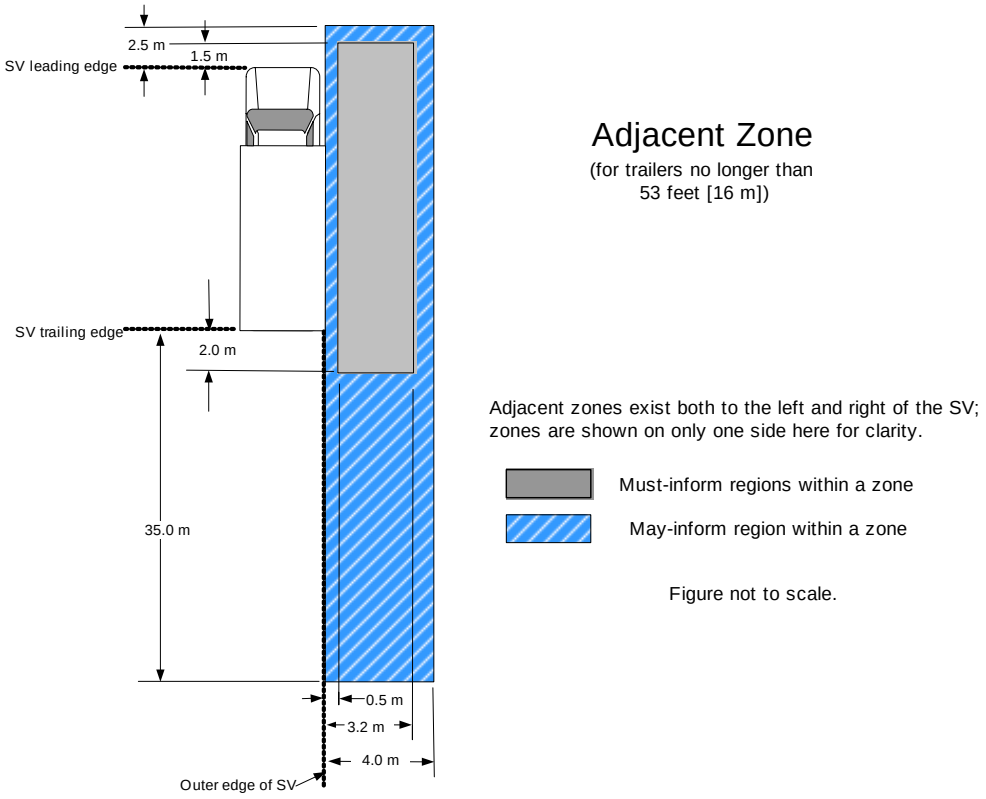
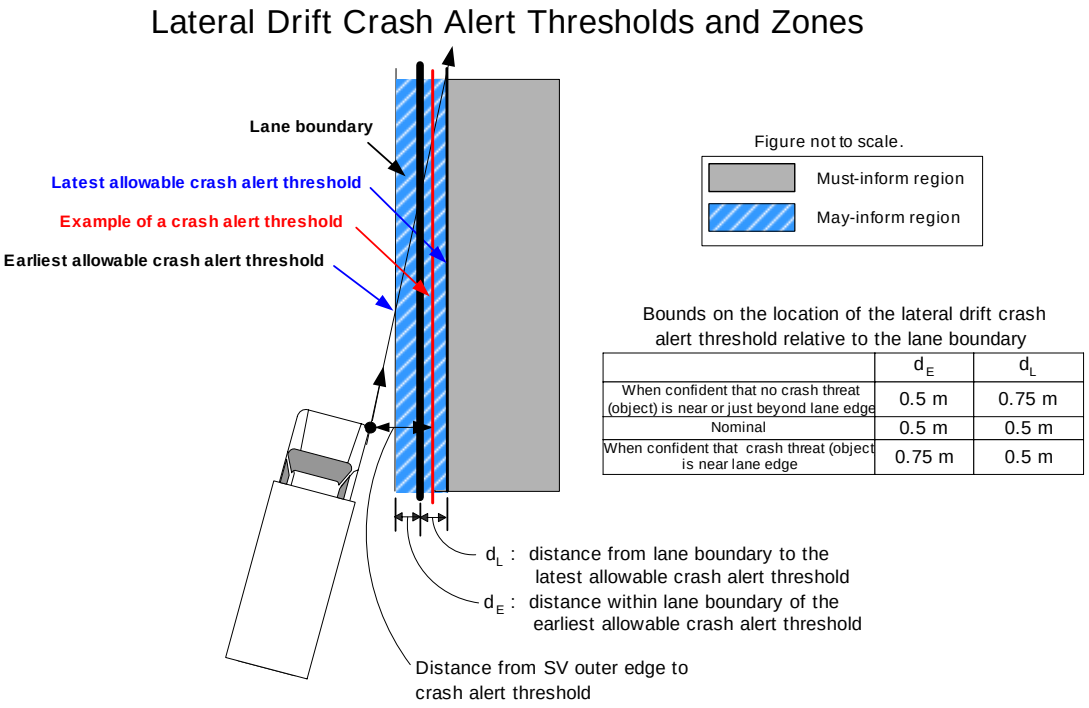


Figure 2. IVBSS heavy-truck platform adjacent zone to address lane-change/merge crashes



	d_E	d_L
When confident that no crash threat (object) is near or just beyond lane edge	0.5 m	0.75 m
Nominal	0.5 m	0.5 m
When confident that crash threat (object is near lane edge	0.75 m	0.5 m

Figure 3. IVBSS heavy-truck platform zones and thresholds to address 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:

- Shall 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
- Shall 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 width of the must-inform region shall be at least as wide as the SV (a large tractor 2.8 meters wide), and shall be aligned with the outer edges of the SV. The width of the may-inform region is confined to the current travel lane of the SV. While changing lanes, the lateral location of the forward zone is not defined for the purposes of this guideline document.

5.1.2.1.2. Forward zone longitudinal extent (alert timing)

Audible and visual advisories are required for indicating the current headway to the forward vehicle (as computed by the time required by the subject vehicle to travel forward and reach the forward vehicle's *current* location). Headway advisories shall occur only for a small set of distinct headway conditions, such as one and two second headway values. Visual advisories are allowed for the detection or the presence of vehicles in the forward zone, or in portions of the adjacent zone.

Crash alerts shall occur no later than when the time to collision to a stopped or slower moving vehicle (as computed by range divided by closing speed) becomes less than or equal to 2.0 seconds.

The minimum required range at which an alert is required is 10 meters. 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 is 67 meters.

5.1.2.2. Adjacent zone crash alerts and advisories

Advisories shall be provided when a vehicle traveling in the same direction as the SV is within the must-inform region of the adjacent zone. Advisories shall also be provided when the time required for a vehicle traveling in the same direction to reach the must-inform region is less than 2.5 s. The time to reach the must-inform region is defined as:

Time to reach must-inform region = (longitudinal distance behind must-inform region) / (longitudinal closing speed of the POV)

A vehicle shall be considered to be a potential adjacent zone threat if either of the above two conditions is satisfied. A vehicle shall not be considered to be a potential adjacent zone threat if the time required for the vehicle to reach the must-inform region is greater than 8 s.

When the SV is changing lanes or merging into another lane and the IVBSS lane boundary tracking is available (Section 4.5), IVBSS shall issue crash alerts at a consistent time to collision with the adjacent vehicle. When a vehicle traveling in the same direction as the SV is a potential adjacent zone threat, a crash alert shall occur no later than when the outer edge of the SV crosses

the lane boundary in the same direction as the threat. In most conditions, a crash alert shall not occur when the outer edge of the SV is not yet in the may-inform lateral-drift region of Figure 3, or equivalently, more than 0.5 meters within the lane. When the IVBSS lane boundary tracking is not available, IVBSS shall issue crash alerts when a vehicle traveling in the same direction is a potential adjacent zone threat and the turn signal is enabled in the direction of the threat.

5.1.2.3. 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 the ISO standard on lane departure warning [8]. The simplest definition of time to line crossing assumes the drift rate is constant:

Time to line crossing = -1 × (distance between the SV outer edge and the crash alert threshold line) / (rate of change of that distance)

IVBSS shall issue crash alerts at a consistent time to line crossing. Furthermore, in most conditions, the crash alert shall occur no later than when the outer edge of the SV crosses into the must-inform region of Figure 2, or equivalently, no more than 0.5 meters outside the lane boundary. In most conditions, a crash alert shall 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 modified 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. For example, forward-zone crash alerts may be delayed if the driver has been previously alerted to the forward threat situation by one and two second headway alerts that occur prior to the specified crash alert minimum time to collision of 2 s.
- 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, shall 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 specified threshold. Even when no object is perceived, however, the alert must 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 and nuisance alerts[1] has been a major issue affecting driver acceptance in previous U.S. DOT field operational tests ([5] and [6]). The following guideline shall be met: The IVBSS false alert rate on the heavy truck platform shall be no greater than 15 false alerts per 100 miles, when traveling over a set of roadway and environmental conditions representative of travel on U.S. freeways and trunk lines (major intercity surface roads on which motor freight traffic typically travels).

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

[1] See the Definitions section for the distinction.

conditions associated with poor performance of certain sensors include rainy nighttime driving, travel on minor neighborhood roads or construction zones, 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.

6 Summary

This document presented the performance guidelines for the heavy-truck platform on the IVBSS project. These guidelines served to guide design, development, and verification specifications for the prototypes to be field tested in this project.

The guidelines in this document address many key features of the system including: 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 (Table 1)
- Alert zone definitions (Figures 1, 2, and 3)
- The domain of applicability for the guidelines as well as guidelines for availability (Table 2)
- Driver controls and system status messages (Table 3)
- Crash alert timing guidelines (Table 4)
- Conditions for advisories (Table 5)
- Maximum crash alert rates (Table 6)

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 issue an excessive number of false alerts.

Table 2. Selected highlights addressing the domain of applicability and guidelines on crash alert availability

Highlighted item	Performance guideline
SV speeds for which guidelines shall hold	25 to 67 mph (11.4 to 30 m/s)
Minimum curve radii for which guidelines addressing the four crash types shall hold	Rear-end crash scenarios: 500 meters Lateral drift road departure crash scenarios: 125 meters Lane-change/merge crash scenarios: 250 meters
Vertical curvatures for which guidelines shall 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 3. Selected highlights addressing driver controls and system status messages

Highlighted item	Performance guidelines
Fleet-manager control settings for crash alert timing (optional)	Timing would be adjusted using two switches: lateral-direction alerts and longitudinal-direction alerts. The guidelines in this document shall be satisfied at any setting.
Driver and fleet manager control settings for auditory alert volume (optional)	Fleet managers and – with the fleet's permission – the driver may be given the ability to vary auditory alert volumes. IVBSS shall not allow the driver to make the auditory alerts inaudible.
Driver control for temporary suppression of crash alerts and advisories (optional)	IVBSS may allow driver-activated temporary suppression of alerts for no more than 6 minutes (2 minutes per driver action).
System status messages	The driver must be informed when performance is significantly reduced (including unavailable states). (Optional) The driver may be asked to take actions to help recover full IVBSS capability (e.g., removing dirt that obstructs key sensors).

Table 4. 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	Maximum required alert range is 67 meters for stopped vehicles.	Time to collision (TTC) = 2.0 seconds
Lane-change/merge with POV in adjacent-zone	0.5 meters within the lane	At the lane boundary
Lateral drift off the road or out of lane	0.5 meters within the lane (0.75 meters within the lane if POV/object is at or beyond lane edge)	0.5 meters beyond the lane (0.75 meters beyond the edge if there is no POV or object beyond lane edge)

Table 5. Conditions for advisories

Advisory	Guidelines constraining advisory
Forward zone POV being detected and tracked (and visual)	Advisories based on time headway are required, including at least a small set with auditory components.
POV in adjacent-lane POV (visual only)	For POV in adjacent zone

Table 6. Maximum crash alert rates

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

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