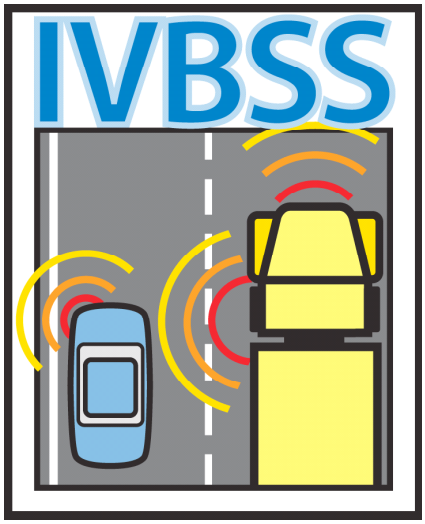

Functional Requirements For The Integrated Vehicle-Based Safety Systems (IVBSS) - Heavy Truck Platform

Prepared by

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for

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 heavy truck and light vehicle platforms. IVBSS is an integrated set of technologies that is intended to help the driver avoid road-departure, rear-end, and lane-change crashes by providing occasional crash alerts and advisories to enhance the driver's awareness of the driving situation.

This document proposes functional requirements for the system to be developed and field-tested on the heavy truck platform. These requirements are generated solely for the system created within this project, and are not intended to be prescriptive for integrated crash systems developed outside the project. The heavy truck platform encompasses class 8 trucks operating with one trailer or without a trailer. The IVBSS on the heavy truck platform addresses the following crash types:

- Road departures due to unintended lateral drift,
- Rear-end crashes, and
- Lane-change and merge crashes due to unsafe lane movements by the heavy truck.

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Acronyms

FCW	Forward crash warning
IVBSS	Integrated Vehicle-Based Safety Systems
LCM	Lane-change and merge warning
LDW	Lateral drift warning
NHTSA	National Highway Traffic Safety Administration
POV	Principal other vehicle
RITA	Research and Innovative Technology Administration
SV	Subject vehicle
UMTRI	University of Michigan Transportation Research Institute
USDOT	U.S. Department of Transportation

Definitions

Advisories: Information that may be provided by the IVBSS to assist the driver in improving or affirming the driver's existing awareness of surrounding traffic, the subject vehicle's position relative to the lane or road edges, and/or the curvature of an upcoming curve. Advisories provide additional information to an alert and attentive driver, and, unlike crash alerts, they do not require the driver to quickly make a specific decision about initiating an evasive maneuver.

Arbitration: The label for the function that provides information to assist the driver in avoiding or reducing the severity of crashes when the driving scenario involves multiple crash threats.

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

Crash alert timing: The amount of time from when the system identifies a potential threat to when it issues a crash alert.

Curve speed warning: The function that provides information to assist the driver in avoiding or reducing the severity of crashes in which the subject vehicle leaves the road on a curve due to excessive speed.

Do-not-warn scenarios: Situations in which the IVBSS system is not to issue crash alerts.

Driver-vehicle interface (DVI): The set of driver controls and displays that accept driver inputs to the IVBSS and provide the driver with crash avoidance and system status information.

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

Field of regard: The geometric space in which the system can detect and track vehicles that pose a potential crash risk.

Forward crash warning (FCW): The function that provides information to assist the driver in avoiding or reducing the severity of crashes in which the subject vehicle strikes the rear end of another vehicle.

Subject vehicle IVBSS: The set of elements necessary to deliver the IVBSS function that are not already part of the subject vehicle.

Lane-change/merge (LCM) warning: The function that provides information to assist the driver in avoiding or reducing the severity of crashes in which the subject vehicle changes lanes, initiates a turn, or merges into traffic and collides with another same-direction vehicle.

Lateral drift warning (LDW): The function that provides advisories and crash alerts to assist the driver in avoiding or reducing the severity of crashes in which the driver unintentionally allows the subject vehicle to drift out of its lane.

Lead vehicle: Synonymous with *principal other vehicle* for scenarios addressing a rear-end crash caused by the subject vehicle striking the rear end of a principal other vehicle.

Maximum required crash-alert range: The maximum distance at which the IVBSS is required to issue a crash alert to help the driver avoid or mitigate a rear-end crash.

Multiple-threat scenarios: Driving situations in which the driving scenario may develop into one of two or more possible crash scenarios.

Nuisance alerts: Crash alerts given in response to an appropriate stimulus, but perceived by the driver as inappropriate due to frequency, timing, modality, intensity, or the particular driving circumstances.

Principal other vehicle: A vehicle sharing the roadway with the subject vehicle. The IVBSS intends to help the driver of the subject vehicle avoid or mitigate a crash with the principal other vehicle.

Project team: The team that is conducting the IVBSS project under a cooperative agreement with NHTSA, as described in Section 1.

Road departure warning: the label for the function that provides information to assist the driver in avoiding or reducing the severity of crashes in which the subject vehicle leaves the roadway. This consists of lateral drift warning and curve-speed warning (see other definitions).

Road edge: The edge of the travel lane that is closest to the road edge (not necessarily the edge of the pavement, since there is often a drivable shoulder beyond the edge of the outer lane).

Subject vehicle (SV): The subject vehicle is a hypothetical vehicle equipped with the IVBSS**.**

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

Volpe Center: The Volpe National Transportation Systems Center of the U.S. DOT's Research and Innovative Technology Administration.

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 heavy truck and light vehicle platforms. The IVBSS project will develop and field test such an integrated system to provide data and experience to address these purposes. The IVBSS project is being conducted under a cooperative agreement between the National Highway Transportation Safety Administration (NHTSA) of the U.S. Department of Transportation (U.S. DOT) and the project team, which consists of the University of Michigan Transportation Research Institute (UMTRI), Visteon Corporation, Eaton Corporation, Cognex Corporation, Honda R&D Americas Inc., and the Battelle Memorial Institute. In addition, the team is supported by the Michigan Department of Transportation.

IVBSS is an integrated set of technologies that is intended to help the driver avoid road-departure, rear-end, and lane-change crashes by providing occasional crash alerts and advisories to enhance the driver's awareness of the driving situation. This document proposes functional requirements for the system to be developed and field-tested on the heavy truck platform. These requirements are generated solely for the system created within this project, and are not intended to be prescriptive for integrated crash systems developed outside the project. The heavy truck platform encompasses class 8 trucks operating with one trailer or without a trailer. A companion report addresses functional requirements for the light vehicle platform. The integrated crash-warning system is called IVBSS in this document, although there is also a slightly different system, developed by a different team, that shall be installed on a light vehicle platform and that is also called IVBSS in that platform's documents. The IVBSS on the heavy truck platform shall address the following crash types:

- Road departures due to unintended lateral drift,
- Rear-end crashes, and
- Lane-change and merge crashes due to unsafe lane movements by the heavy truck.

IVBSS incorporates crash-alert technologies that have been the subject of extensive efforts within the automotive and heavy truck industries as well as within the U.S. DOT. Major programs supported by the U.S. DOT have addressed forward crash warning (Ervin et al., 2005; General Motors, 2005; Kiefer et al., 2003; Kiefer et al., 1999), road-departure crash warning (LeBlanc et al., 2006; Pomerleau et al., 1999), and lane-

change/merge systems (Talmadge et al., 2000). The IVBSS program furthers this work by addressing the integration of multiple crash-warning systems in several ways:

- Through developing and field testing an approach to provide the driver a single, coherent interface that integrates information from multiple systems
- Integrating data from multiple sensors to improve the performance of the individual crash-warning components
- Addressing additional crash types through the ability to treat multiple-threat scenarios, in which more than one potential crash conflict is present or developing.
- Sharing approaches, technology, and insights between the heavy truck and light vehicle teams.

The requirements for the heavy truck platform differ somewhat from those developed for the light vehicle platform. This reflects the difference between the vehicle platforms, the users of each of the platforms, the users' priorities associated with these technologies, the operating environments, and the differences in crash experiences relevant to these technologies. Overall, however, the requirements and development processes are closely linked within the project structure, so that each team considers similar issues and the platforms pursue substantially different approaches when platform-related considerations warrant the differences.

These functional requirements do not encompass elements of the IVBSS that are necessary only to support the field operational testing that will occur in this project. For example, the IVBSS must supply data signals to be recorded by an onboard data collection system, as required by the analysis needs of the project. While this capability is included in the IVBSS being built for this project, the requirements do not address this concern.

Finally, the functional requirements in this document have been generated by the project team and do not necessarily represent the views or policies of the U.S. DOT or NHTSA.

2 Crash Scenarios and Do-Not-Warn Scenarios

Using the results of studies carried out by the Volpe National Transportation Systems Center, key crash scenarios have been identified for road-departure, rear-end, and lane-change crash types (Najm & Smith, 2007). The functional requirements presented in Sections 3 through 9 of this document are developed so that the IVBSS provides appropriate behavior in these crash scenarios. In addition, since the IVBSS must provide behavior that is on the whole acceptable to the driver, a set of "do-not-warn scenarios" is defined to describe non-crash scenarios in which the IVBSS should not provide the driver with crash alerts. These are often situations with the potential for a false alarm or a nuisance alert, and the requirements associated with these scenarios are intended to improve driver acceptance. The use of do-not-warn scenarios is consistent with previous functional requirements work (Kiefer et al., 1999); the term "do-not-warn scenarios" is synonymous with the term "operational scenario" used in that work. The remainder of this section presents the crash scenarios and describes characteristics of the do-not-warn scenarios. Those scenarios are presented in companion documents from the IVBSS program that present objective test procedures for IVBSS.

2.1 Rear-End Crash Scenarios

This section describes the crash scenarios that are most important for the heavy truck rear-end crash problem. First, two definitions are provided:

- Subject vehicle (SV): The vehicle (heavy truck) equipped with the IVBSS.
- Principal other vehicle (POV): A vehicle sharing the roadway with the subject vehicle that may pose a crash threat.

The IVBSS intends to help the driver of the subject vehicle avoid or mitigate a crash with the principal other vehicle. Table 1 indicates those rear-end crash scenarios that will be considered the primary scenarios for the IVBSS requirements. This table is derived from an analysis of crashes in 2000-2003 General Estimates System (GES) databases that was performed by the Volpe Center for NHTSA (Najm & Smith, 2007). There were 154,000 crashes in which the striking vehicle was a truck and another 100,000 crashes in which the heavy truck was struck. If the latter crashes are not considered, then the scenarios can be broken down as shown in Table 1.

The first three scenarios address situations in which the subject vehicle is not attempting a maneuver (e.g., not passing), and approaches a principal other vehicle from behind. These three scenarios are distinguished from one another by the speed and

deceleration of the principal other vehicle. The fourth item represents the scenarios where the SV is following a POV and making a maneuver such as: passing, leaving a parked position, entering a parked position, turning right, turning left, making a U-turn, backing up, changing lanes, merging corrective action, or other motions.

As the data indicates, almost ninety percent of these crashes involve the SV approaching and striking a vehicle in the same lane (scenarios 1 through 3). The most common is when the POV is stopped (scenario 1), although it may be true that many of these stopped vehicles had come to rest very shortly before impact. Although the fourth category of scenarios, where the SV is making a maneuver, account for only 6.5% of the crashes, they are considered meaningful enough to be included in the crash scenario set for development of the requirements. The scenarios described in Table 1 were used as the basis for development of rear-end crash scenarios for on-track testing.

Table 1. Rear-end crash scenarios for developing functional requirements for the IVBSS heavy truck platform

Index	Crash Scenario	Frequency	Percent
1	POV is stopped	66,000	43%
2	POV is decelerating	37,000	24%
3	POV is moving at constant speed	34,000	22%
4	SV is following and making a maneuver	10,000	6.5%
--	Other rear-end crash scenarios not considered primary scenarios for requirements development	7,000	4.5%
--	Total	154,000	100%

The desired effect of IVBSS driver alerts in rear-end scenarios is to bring the driver's attention to the developing conflict so that they initiate an evasive maneuver such as braking and/or steering in order to avoid the crash. The difference between the evasive maneuver with and without a crash alert then constitutes the effect of the IVBSS in these scenarios.

There may be benefits of these driver alerts beyond the scenarios in Table 1, since there are crashes that begin as rear-end crash scenarios but, due to an unsuccessful driver maneuver, result in other crash types, such as road-departure crashes.

2.2 Road-Departure Crash Scenarios

The 2000-2003 GES statistics indicate that there were approximately 110,000 crashes in which a truck ran off the road. The scenarios vary significantly, with about two-thirds of the crashes due to a simple drift-off event, while the others were related to loss of control, maneuvers including evasive maneuvers associated with the driver avoiding other crash types, and turns. Table 2 shows the three main scenarios most relevant to IVBSS functional requirements development (Najm & Smith, 2007). The scenarios described in Table 2 were used as the basis for development of road-departure crash scenarios for on-track testing.

Table 2. Road-departure crash scenarios for developing functional requirements for IVBSS heavy truck platform

Index	Crash Scenario	Frequency	Percent
1	SV drifts from road on straight road segment	46,000	25%
2	SV drifts from road on curve	22,000	13%
3	SV is initiating a maneuver	46,000	28%
--	Other road-departure scenarios not considered primary scenarios for requirements development	55,000	33%
--	Total	165,000	100%

The benefit of IVBSS in scenarios 1 and 2 would derive from road-departure warnings prompting drivers to return their attention to lane-keeping activities. There may also be benefits in scenario 3, which refers to a loss-of-control situation when the SV is initiating a maneuver. For example, approximately 2,000 road-departure crashes in 2003 were associated with a truck avoiding a rear-end crash and departing the road edge. A portion of these crashes could be addressed by the rear-end crash warning component of an IVBSS system.

2.3 Lane-Change Crash Scenarios

Najm & Smith (2007) also provides data that was used to directly derive Table 3, which shows the primary scenarios for requirements development associated with crashes due to unsafe lane changes or merges initiated by the IVBSS-equipped vehicle. The total annual number of these crashes is approximately 311,000, which includes 42,000 crashes

associated with unsafe lane changes or merges and 12,000 with unsafe turns in which the truck encroaches on another adjacent vehicle.

Table 3. Lane-change/merge crash scenarios for developing functional requirements for the IVBSS heavy truck platform

Index	Crash Scenario	Frequency	Percent
1	SV changes lanes and/or passes and encroaches on an adjacent vehicle	83,000	26.7%
2	SV drifts & encroaches on an adjacent vehicle	34,000	11%
3	SV change lanes or passing to unknown adjacent lane	5,000	1.6%
4	SV merges and encroaches on an adjacent vehicle	7,000	2.3%
5	SV turns & encroaches on an adjacent vehicle	53,000	17%
--	Other scenarios not considered primary scenarios for requirements development	129,000	41%
--	Total	311,000	100%

The benefit of IVBSS in scenarios 1, 2, and 3 would derive from crash alerts that prompt the truck driver to adjacent hazards during lane changes. Scenario 4 would be addressed by the IVBSS providing assistance during merging maneuvers, and scenario 5 would call for assistance as the truck initiates turns and has the potential to encroach on adjacent-lane vehicles.

2.4 Multiple-Threat Crash Scenarios

This section addresses multiple-threat scenarios, where situations have the potential to develop into one of two or more possible crash scenarios. This may occur because of the development of simultaneous threats or because the driver uses a maneuver to avoid one crash conflict that creates a second type of crash conflict. Multiple-threat crash scenarios are useful to consider; because the IVBSS has the ability to sense crash threats of many types, the system requirements must consider how to best provide alerts to the driver in these more complex circumstances.

Multiple-threat scenarios are not directly derivable from GES crash data since the coding of the crashes often does not address the entire sequence of events, but only the

developments before the crash that actually occurred. Thus these scenarios were developed based on judgments that the scenarios were both realistic in nature and also highlighted important elements for an integrated crash-warning system to consider. The scenarios that are selected for validation are shown in Table 4, with illustrations of each following in Figure 1.

Table 4. Multiple-threat crash scenarios for developing functional requirements for the IVBSS heavy truck platform

Index	Crash Scenario
1	SV approaches a slowing vehicle in its lane while attempting a lane change into occupied lane
2	SV aborts lane change into occupied lane, then encounters a slowing vehicle in its original travel lane, and considers resolving the conflict by moving on to a clear shoulder to avoid both vehicles.

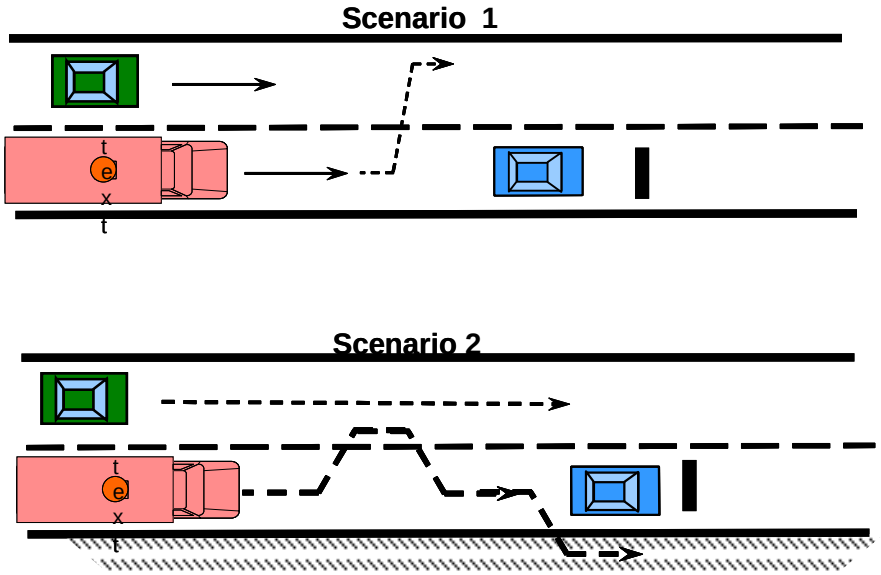

Figure 1. Two multiple-threat scenarios

2.5 Do-Not-Warn Scenarios

In order to achieve sufficient acceptance of IVBSS by the trucking fleet operator and the drivers, the IVBSS must avoid issuing an excessive number of alerts in situations that fleet operators and/or drivers do not consider to be threatening situations. A “do-not-

warn scenario" is a driving situation in which IVBSS should not issue a crash alert. Do-not-warn scenarios are used to address two types of undesirable crash alerts: false alarms and nuisance alerts.

False alarms are defined in Campbell, et al. (2007) as "alerts that are triggered in the absence of an appropriate stimulus." These are typically caused by sensor or system perception errors that suggest a threat where one does not exist, and are characterized by the system having a false view of its current situation. Examples of false alarms include forward crash warnings triggered by overhead bridges and out-of-path vehicle or road departure warnings triggered by a misperception of the location of the lane edge.

Do-not-warn scenarios also address nuisance alerts, which are caused by an appropriate crash threat but "are perceived by the driver to be inappropriate due to some aspect of their implementation such as their frequency, timing, intensity, or modality" (Campbell et. al, 2007). Nuisance alerts also occur when the driver simply does not perceive a threat; this is often influenced strongly by the driving circumstances (Ervin et. al, 2005). Table 5 shows examples of false alarms and nuisance alerts. The do-not-warn scenarios are detailed in the IVBSS Heavy Truck System Verification Test Plan document (UMTRI, 2008).

Table 5. Examples of false alarms and potential nuisance alerts

Alert Occurs While…	Potential Type of Crash Alert Triggered	Type of Alert
Subject vehicle passes stationary roadside object or overhead object.	Rear-end	False (invalid object triggers alert)
Remote sensing provides a false return where no vehicle exists.	Rear-end or Lane-change/merge	False (invalid object triggers alert)
Subject vehicle drives on pavement with many longitudinal seams not aligned with lane edges.	Road departure (lateral drift) or lane change	False (mistaken lane boundaries)
Subject vehicle is approaching a slower vehicle in a manner that the driver commonly employs.	Rear-end	Nuisance (too early)
Subject vehicle is closing on a lead vehicle that is leaving the lane.	Rear-end	Nuisance (paths do not intersect)
Subject vehicle is weaving slightly within the lane but near the road edge.	Road departure (lateral drift)	Nuisance (driver feels no threat)
Intentional road departure with turn signal applied.	Road departure (lateral drift)	Nuisance (driver intends to cross edge)
Intentional lane change with turn signal applied.	Unsafe lane change	Nuisance (driver intends to cross edge)

3 System-Level Functional Requirements

This section presents system-level functional requirements. Throughout this document, "shall" is used when the requirement must be satisfied, and "may" is used to indicate that an IVBSS system is allowed to provide the associated behavior.

3.1 Objective of the IVBSS

The IVBSS shall be designed to achieve two objectives:

- To maximize the potential safety benefits of the information, and
- To earn acceptance of the system by fleet operators and drivers so that the safety benefits may be realized.

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

a) Rear-end crashes in which the subject vehicle strikes the rear-end of another vehicle,

b) Lateral-drift road-departure crashes in which the driver of the subject vehicle unintentionally allows the vehicle to drift off the road,

c) Lane-change crashes in which the subject vehicle changes lanes and collides with another vehicle moving in the same direction, and

d) Merging crashes in which the subject vehicles merges into traffic and collides with another vehicle.

The scenarios to be addressed were identified in Section 2. The IVBSS may provide potential safety benefits in scenarios besides those in Section 2.

3.2 Primary Function and Scope of IVBSS

3.2.1 Primary function of IVBSS

The 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), and
- Advisories (some required and some optional).

3.2.1.1 Crash alerts

The IVBSS shall provide information that helps the driver be aware of a potential crash conflict, so that the driver may decide both whether and/or how to initiate an evasive maneuver.

3.2.1.2 Advisories

The IVBSS may also provide the driver with advisories that may assist the driver in decision-making to reduce the likelihood that a crash conflict will develop. If advisories are provided to the driver, this information shall be intended to reduce the frequency or severity of conflicts that would otherwise develop. An example of an advisory is a visual indicator provided to the driver when a same-direction vehicle is within the blind spot of the subject vehicle. An advisory is different from a crash alert in that it intends only to provide additional information to an alert and attentive driver, and is not meant to indicate the need for the driver to quickly make a specific decision about initiating an evasive maneuver.

3.2.1.3 System status information

The third type of information that the IVBSS shall present is system status information. The IVBSS shall inform the driver of its operational status; the details are presented in section 8.5.

3.2.2 Scope of the IVBSS

3.2.2.1 Presentation of information

The crash alerts shall be designed to assist the driver in quickly directing attention to the driving task and especially the potential crash risk.

The timing of crash alerts shall be designed with a primary goals of (a) allowing drivers who are unaware of the potential crash risk enough time to react, assess the situation, and decide whether and how to initiate and complete an evasive maneuver that avoids or mitigates the crash, and (b) helping drivers maintain margins of safety by keeping within the lane, staying at safe following distances, and by being aware of adjacent-lane vehicles.

In scenarios in which the information available to the IVBSS cannot distinguish situations with potential crash risk from non-threatening situations, the timing is allowed to be later in order to reduce the number of crash alerts that may be perceived as

nuisances by the driver. In these cases, the system shall be designed to maximize the harm reduction that the system provides.

The crash alerts shall not advise the driver on whether or how to initiate an evasive maneuver. This requirement recognizes that an aware driver remains the best decision-maker about whether or how to initiate such a maneuver.

3.2.2.2 Use of vehicle control in IVBSS

The IVBSS shall not provide automatic control of the vehicle.

This statement addresses the scope of the IVBSS and the requirements in this document, and is not meant to prohibit or advise against other systems that employ active control of the vehicle (e.g., the automatic application of emergency braking) to mitigate rear-end crash severity.

3.2.2.3 Autonomy

The IVBSS shall be fully functional in today's driving environment and independent of additional equipment or features being added to the roadway infrastructure or extra equipment or capabilities installed on vehicles other than the subject vehicle.

3.3 System-Level Functional Requirements for IVBSS

3.3.1 Crash alert functions and definitions

The IVBSS shall have three component functions that together satisfy the requirements of Section 3.1. These functions are defined below along with the scenarios they address:

3.3.1.1 Forward crash warning

Forward crash warning (FCW) provides information to assist the driver in avoiding or reducing the severity of crashes in which the subject vehicle strikes the rear end of another vehicle.

3.3.1.2 Lateral drift warning

Lateral drift warning provides information to assist the driver in avoiding or reducing the severity of crashes in which the subject vehicle unintentionally drifts off the road edge. (See Definitions on page viii for the definition of road edge.) Lateral drift warning may also provide the driver with a crash alert or an advisory when the vehicle crosses a lane boundary; more discussion of this is provided in Section 5.

3.3.1.3 Lane-change/merge warning

Lane-change/merge (LCM) warning provides information to assist the driver in avoiding or reducing the severity of crashes in which the subject vehicle changes lanes, initiates a turn and encroaches on another vehicle in an adjacent lane, or merges into traffic and collides with another same-direction vehicle.

3.3.1.4 Arbitration

There shall be an arbitration function that is transparent to the driver, and which identifies and addresses multiple-threat scenarios. Arbitration shall manage the provision of crash alerts and advisories such that the driver is not overloaded or confused by multiple and possibly conflicting information from the IVBSS.

3.3.1.5 IVBSS

The IVBSS is defined as the sum of elements necessary to deliver the IVBSS function that are not already part of a vehicle.

3.3.2 Achieving IVBSS functionality

This section introduces the relationship of the IVBSS with the vehicle, the driver, and the environment. This section also introduces the high-level functional elements within the IVBSS.

3.3.2.1 Interaction with elements outside IVBSS

To deliver the functions described in Section 3.3.1, the IVBSS interacts with the subject vehicle, the driver, and the roadway and traffic environment. Figure 2 illustrates these interactions, which lead to the following requirements:

a) The IVBSS shall interface directly with the driver by providing crash alert displays and (optionally) advisories. The IVBSS may accept driver inputs to the IVBSS, per Section 8.1.

b) The IVBSS shall receive signals from the subject vehicle that include information about vehicle motion and the driver's control inputs to the vehicle, as well as other information (as described in a later section).

c) The IVBSS shall sense or obtain information about the roadway geometry, roadway characteristics, and position and motions of relevant nearby vehicles, and may need to gather limited information about other obstacles. This is elaborated upon in Section 6.1.

3.3.2.2 Major functional activities within the IVBSS

The IVBSS shall include four major activities, as represented by the numbered elements in Figure 3:

1. Sensing and perception activities shall be included within the IVBSS. These address measurement or data retrieval to assess the subject vehicle state, driver control actions (such as steering and braking), roadway information, and data on nearby vehicles and other obstacles (represented by element 1 in Figure 3). Descriptions of required data are provided in Sections 4, 5, and 6.
2. Situation characterization and threat assessment activities shall be included within the IVBSS. These determine whether it is appropriate to provide crash alerts and/or an advisory to the driver. This is represented by element 2 in Figure 3 and will be described in more detail in Sections 4, 5, and 6.
3. Presentation of information to the driver shall be included within the IVBSS (represented by element 3 in Figure 3). This will be described in more detail in Sections 4, 5, 6, 7, and 8.
4. System management functions shall be included within IVBSS to assess and maintain IVBSS operation. This includes interfacing with the driver regarding any driver inputs that the IVBSS may have, as well as providing the driver with the necessary information to understand the operational state of the system (element 4 in Figure 3). This is noted in Section 9. Section 8.1 addresses driver or fleet operator inputs to the IVBSS. Section 8.5 addresses system status information provided to the driver.

3.3.2.3 Sensing and perception

The IVBSS shall measure, store, and/or obtain data on the following elements: driver inputs to the IVBSS, signals from the subject vehicle (including vehicle control inputs from the driver), and data needed to characterize roadway geometry and other roadway characteristics, and data on nearby vehicles and other obstacles.

The elements listed above are described in Sections 4 – 7 in the context of the specific crash alert functions that are required.

3.3.2.4 Functional elements within situation characterization and threat assessment

Situation characterization and threat assessment within the IVBSS shall include the following elements, which are also shown in Figure 4:

a) Estimation of the roadway geometry (element 2.1),

b) Use of data from Section 3.3.2.3 to characterize the state of the driving circumstances and compute necessary predictions of the future state (element 2.2),

c) Assessment of the threat level, resulting in a request for a driver alert or situational information cue (element 2.3), and

d) Arbitration of alerts in situations where more than one type of driver alert is being considered (element 2.4).

The following elements may be included in the IVBSS, but are not required:

e) Estimation of some aspects of the driver's state (element 2.5), and

f) Generation and use of historical information that may be useful in reducing the number of false alarms (element 2.6).

The elements listed above are described in more detail in Sections 4 – 7 in the context of the specific crash alert functions that are required.

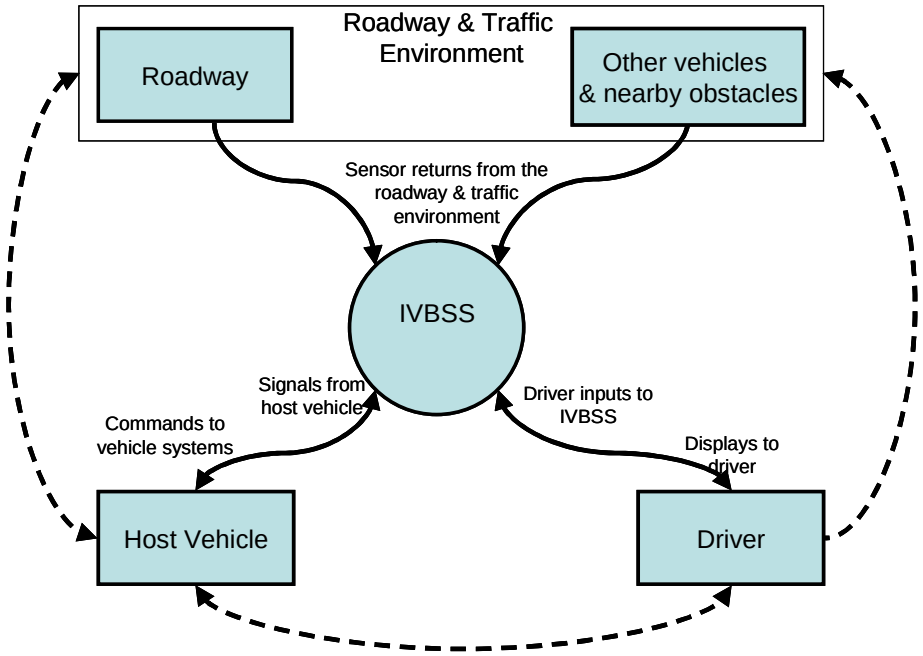

Figure 2. Interaction of the IVBSS with external elements

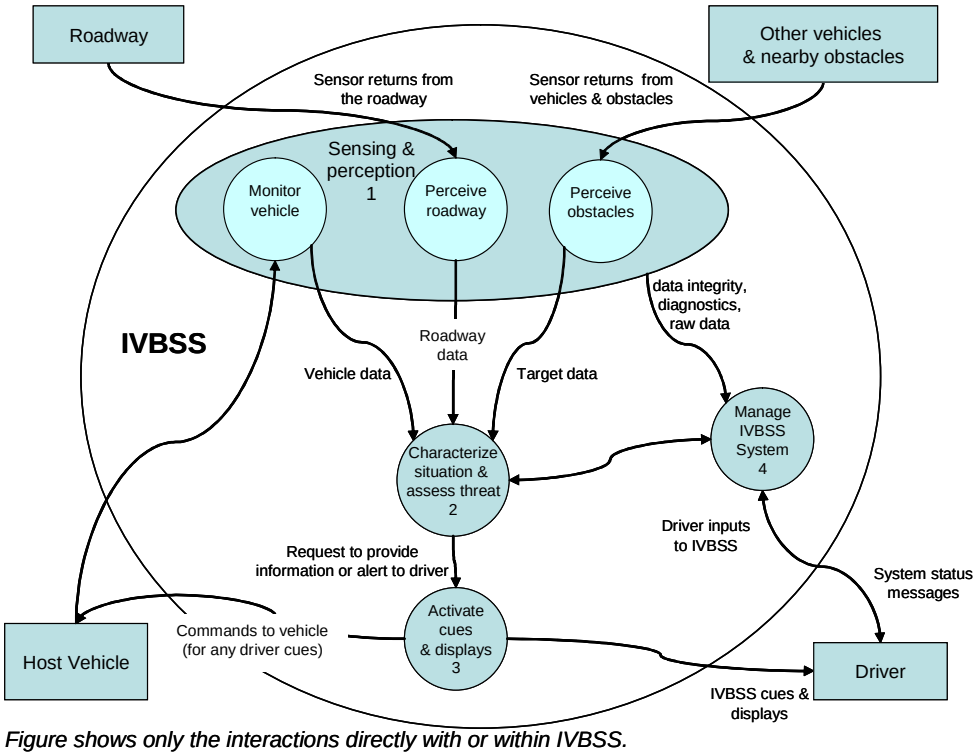

Figure shows only the interactions directly with or within IVBSS.

Figure 3. Key functional elements within the IVBSS

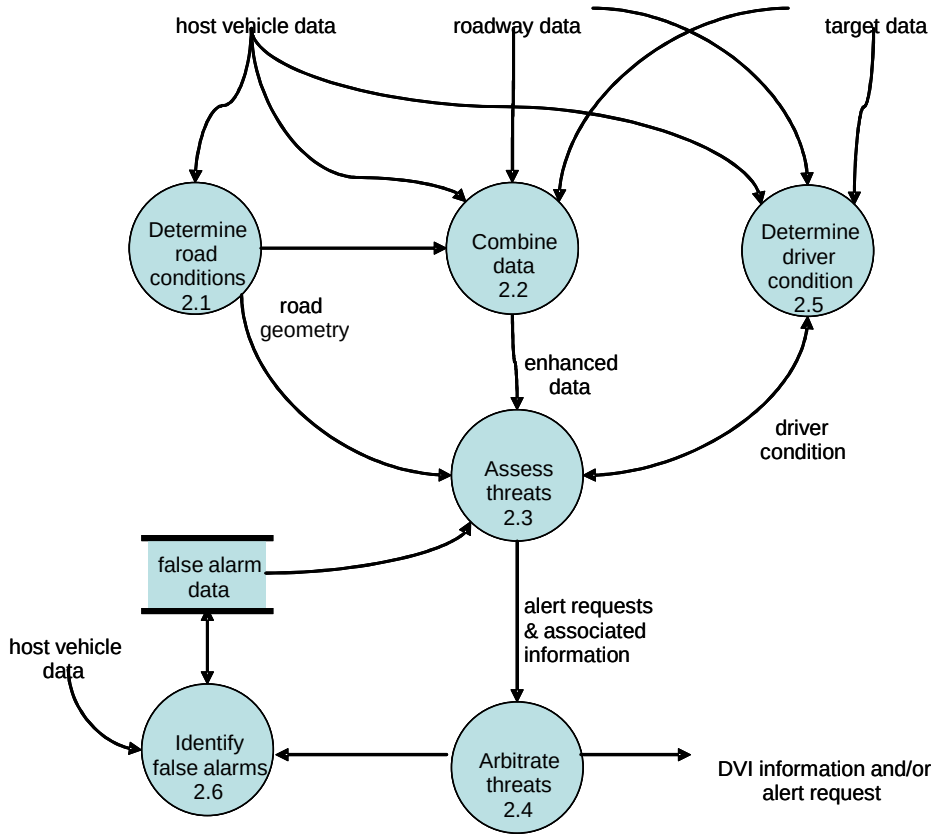

Figure 4. Elements within situation identification and threat assessment

3.3.2.5 Driver-vehicle interface functions

The IVBSS shall provide crash alert information and advisories to the driver.

3.3.2.5.1 Properties of the presentation of information

There are three high-level properties that are necessary:

a) The IVBSS information shall be presented to the driver so that the message is salient and intuitive, and provides the safety benefit of enhancing situation awareness and increasing the likelihood of avoiding or reducing the severity of the targeted crashes.

b) The driver shall be neither confused nor distracted from the driving task by the information.

c) The information from multiple crash-alert functionalities shall be integrated into a seamless and intuitive interface. (See Section 8.)

Further properties of the driver-vehicle interface (DVI) that are required for particular types of targeted crashes are discussed in Sections 3 – 7. More general properties of the driver-vehicle interface to promote the seamless interface are discussed in Section 8.

3.3.2.5.2 Fleet operator and driver inputs

There are two high-level requirements addressing fleet operator and driver control inputs to IVBSS:

a) Controls may be employed to allow the driver or fleet operator to adjust the system behavior, but the range of system behavior shall remain within the performance requirements stated here.
b) The driver shall not be able to turn off the IVBSS but may be able to temporarily suppress crash alerts for a short period, e.g., several minutes, per Section 8.1.

Additional driver-vehicle interface requirements are presented in later sections in the context of the individual crash alert functions, as well as in Section 8. System status information is described in Section 8.5.

3.4 Domain of Applicability of Requirements

3.4.1 Subject vehicle characteristics

The IVBSS for the heavy truck platform shall operate as indicated herein when installed on a class 8 tractor with zero or one trailers, as described in Section 1.

3.4.2 Roadway characteristics

The requirements within this document shall apply while the subject vehicle is traveling on a paved roadway managed by public agency(s) or while on a privately-operated toll road.

3.4.2.1 Exempted roadway types

The functional requirements do not need to be satisfied when traveling on other roadways or surfaces, such as private roads, driveways, parking lots, and unpaved roads. Operation of IVBSS is permitted on all roadway types.

3.4.2.2 Exempted roadway geometries

The IVBSS or some of its alert functionalities are allowed to become unavailable when the roadway geometry satisfies one or more of these exceptions:

a) The subject vehicle and/or a relevant principal other vehicle is traveling on a curve with a radius that is below a threshold value.
b) The forward crash warning system and the lateral drift warning system need not operate on roadway segments where the roadway crests with a negative vertical curvature that is so great that the driver cannot see a vehicle traveling ahead even when that vehicle is close enough to pose a potential rear-end crash threat.

Consult Sections 4, 5, and 6 for further exceptions related to the individual crash alert types.

3.4.3 Characteristics of objects posing a potential crash threat

For this document, the requirements that address IVBSS performance in potential crashes with other vehicle objects shall be met when the object is a motor vehicle that is licensable for use on public roads. This set of objects includes motorcycles. The IVBSS will not be evaluated on its performance in regards to other potential crash threats, including pedestrians, pedalcyclists, or animals on the roadway. However, a system that meets the requirements for licensable motor vehicles may also provide benefit for pedestrians, cyclists, and animals in some circumstances.

3.4.4 Interactions with other emerging technologies

It is beyond the scope of this effort to develop requirements that fully address interactions of the IVBSS with all available or emerging technologies. Developments in new technology that may affect vehicle control or a driver's attention or situation awareness include, but are not limited to, the following: adaptive cruise control, automatic lane-keeping assist (limited-authority), forward-crash mitigation through automatic braking, automatic control systems to correct lane or road departures, and wireless communications with other vehicles or the roadside, telematic systems that may complicate the driver-vehicle interface, and workload management systems.

3.4.5 Operating speeds

The following requirements address requirements on subject vehicle speeds at which the IVBSS shall function:

a) IVBSS shall be available to issue alerts when the subject vehicle speed exceeds a minimum threshold. For the heavy truck platform, this minimum operating speed may be lower for lane-change/merge functionality since turning crashes are an important component of the lane-change/merge crash problem, and they occur at lower speeds.

b) The IVBSS may have an upper bound on the speed at which it operates, so that either the system may become unavailable above that speed or the system may operate at a reduced level. Higher speeds can lead to a reduced ability to sense the roadway far enough ahead for suitable performance. This may include a reduced ability to predict the identity or motion of objects at distances that are relevant to the potential for a crash.

3.4.6 Operation in the presence of precipitation

The IVBSS shall meet all requirements in dry conditions. The system shall inform the driver of any reduced capability that precipitation induces.

3.4.7 Operation in poor visibility conditions

The IVBSS shall meet all requirements in good visibility, both in daytime and in nighttime. The IVBSS shall inform the driver of any reduced capability that poor visibility induces such that the system is not confident that performance would meet the requirements in this document.

3.4.8 Operating temperatures

The IVBSS shall satisfy the performance requirements over a range of ambient temperatures that is consistent with the required range that applies to other electronic technologies onboard the vehicle platform.

3.5 Operating States and Availability

3.5.1 Operating states

The IVBSS shall be considered to have two operational states:

- Operational – all hardware is operational and all communications and software processes are operating without critical faults.
- Not operational – all other conditions.

3.5.2 Availability

One or more crash alert functionalities within the IVBSS are said to be available if (1) the system is in an operational mode, (2) the system has confidence in its ability to perceive crash risks and command driver alerts, and (3) the system is allowed by its own system logic to provide crash alerts and advisories when its internal criteria are satisfied.

3.5.2.1 Partial availability of IVBSS

The IVBSS is comprised of several crash alert functionalities, per Section 3.3.1. The following addresses the ability of some crash alert functionalities to function while one or more of the other crash alert functionalities are not available:

a) IVBSS may function such that some of the crash alert types are operational and available and others are either not operational or not available. For example, the lateral-drift crash alerts may become unavailable if snow is obscuring lane edges for a vision-based system. When this is the case, the other functionalities may be allowed to provide the driver with cues.

b) If the arbitration function becomes unavailable (due to hardware or software faults, for instance), the entire IVBSS shall become non-operational.

3.5.2.2 Situations in which IVBSS may be unavailable

The system shall be available at all times while the system is operational, except when one or more exceptions apply. Most exceptions are listed below, but others appear elsewhere in this document. The IVBSS or one or more of its crash alert functionalities may become unavailable due to the following situations:

a) Occasional sensor obstructions or outages, e.g., dirt or ice on radar.
b) Low confidence in estimate of threat, e.g., poor lane markings,
c) Operating conditions that do not satisfy the operating conditions listed earlier, e.g., vehicle speed is below the minimum operating speed,
d) When the IVBSS intentionally suppresses system function, e.g., FCW alerts may be suspended while the driver is applying the brake, and
e) Failures in the systems used to sense the roadway, subject vehicle motion, and/or potential crash threats.

3.5.2.3 Informing driver of unavailable system

The system shall inform the driver when the system is unavailable to provide any type(s) of crash alerts, or is operating at a reduced level. The system may continue providing alerts at a reduced level of performance as long as drivers are made aware that limitations in performance are in effect.

3.5.3 System states

The table below shows system states of the IVBSS.

Table 6. System state possibilities of the IVBSS

IVBSS System State Possibilities
Not operational
Operational - but no crash alert types are available
Operational - with all crash alert types available
Operational - with some crash alert types available and some not available

3.6 False alarms and Nuisance Alerts

The IVBSS shall avoid generating an excessive number of false alarms and/or nuisance alerts in order to achieve driver acceptance.

4 Functional Requirements to Address Rear-End Crashes

This section presents functional requirements for the portion of IVBSS that provides crash alerts and advisories to drivers to assist them in avoiding or reducing the harm associated with rear-end crashes. This portion of IVBSS is referred to as FCW, per Section 3.3.1.1.

4.1 Sensing Requirements

The IVBSS requires data in order to characterize the driving circumstances. This involves measurements from IVBSS sensors, communications with the vehicle, use of static and dynamic onboard data sources, and possibly other sources. Some data is directly useful in its raw form, but much of the information needed to characterize the driving situation requires the combination of data from multiple sources. This section focuses on the collection of data from the individual sources: subject vehicle, roadway, and other vehicles or nearby obstacles. Section 4.2 addresses the combination of the data.

4.1.1 Sensing subject vehicle information and driver control inputs

The following requirements address signals gathered directly from the subject vehicle:

a) The IVBSS shall obtain data from the subject vehicle and from sensors dedicated to the IVBSS in order to support estimates of the following: subject vehicle state, driver inputs to the vehicle controls, and predicted subject vehicle path. Data may also be obtained to support other computations such as perceptions of intended driver maneuvers.

b) The data to be obtained shall include the following: subject vehicle speed, yaw rate, and driver brake switch. Other data may, of course, be desirable, including turn signal use, subject vehicle longitudinal acceleration, driver throttle control, wiper state, steering wheel angle, ambient temperature, and more.

4.1.2 Sensing roadway geometry and characteristics

These requirements address the collection or acquisition of information about the roadway:

a) The IVBSS shall be capable of collecting information to characterize roadway geometry and other attributes as necessary to support situation characterization and threat assessment.

b) The data to be obtained shall include the following: heading of the road relative to the vehicle axes and road curvature.

c) These data may also include road functional class and number of lanes.

Sources of this data may include remote sensors, onboard digital maps, and historical data retained within IVBSS. Additional information about the roadway may be computed with the assistance of subject vehicle and/or target data.

4.1.3 Sensing objects and characterizing object type and motion

The IVBSS shall be capable of collecting information to characterize the location and motion of vehicles that pose the potential for a rear-end crash, relative to the subject vehicle. The data shall also support the prediction of the paths of the other vehicles.

This information may be obtained in part from remote sensors in conjunction with other data, such as vehicle motion and roadway information. Note that information about other vehicles and nearby objects may also be collected to assist in the situation characterization for other crash alert functions.

4.1.3.1 Detection and tracking of potential threats

The IVBSS shall be capable of detecting and tracking same-direction vehicles and stopped vehicles.

4.1.3.2 Characterizing potential threats

The IVBSS shall be capable of determining whether or not objects are principal other vehicles (same-direction vehicles or stopped vehicles that may pose a potential crash risk).

4.1.3.3 Object motion

The system shall determine the following kinematic variables associated with principal other vehicles that may pose a forward crash hazard: position relative to the subject vehicle, and relative speed.

4.1.3.4 Field of regard

The field of regard is the space in which the system can detect and track potential rear-end crash objects. The field of regard shall include the travel lane (or shoulder) on which the subject vehicle is traveling. The field of regard shall also include portions of adjacent lanes as required to address the key scenarios described in Section 2.

The system shall be able to detect and track vehicles within a field of regard that has a longitudinal extent that balances the limits of capability of state-of-the-art technology with the need to detect slow or stopped vehicles at substantial distances in order to provide timely information to the driver. This longitudinal extent shall be stated as the maximum required crash-alert range.

The value of the maximum required crash-alert range may be different depending on whether the potential crash threat is stopped or moving, due to the additional challenges of discriminating stopped vehicles from non-threatening stationary objects.

Requirements about the field of regard shall be satisfied for straight roads as well as roads with curves that satisfy the criteria given in Section 3.4.2.2.

4.1.4 Estimating road condition parameters

The system shall use data from the subject vehicle and/or from sensors associated with the IVBSS to determine whether the road conditions may require the driver to receive earlier crash alerts or to be presented with a different advisory. Indications of wetness or iciness on the road may be especially useful. Examples of implementations to satisfy this requirement are simple uses of windshield wiper state and ambient temperature to decide that there is a reasonable possibility of iciness on the road surface.

4.1.5 Sensing driver attributes

The system may use subject vehicle data, roadway data, and target data to determine the value of parameters that characterize aspects of the driver's state. These parameters may be used to adjust the presentation of IVBSS crash alerts and/or advisory information to the driver, so long as the performance requirements are satisfied. Examples of the use of driver state may be the perception that a driver is fatigued to increase the distance at which a rear-end crash alert is presented.

4.2 Situation Awareness and Threat Assessment Requirements

4.2.1 Situation characterization

The system shall integrate vehicle data, target data, roadway data, and road conditions data to develop an awareness of the driving situation suitable for making threat assessment decisions.

4.2.1.1 Object classification

The following addresses classification of objects that may pose a risk of a rear-end crash:

a) The IVBSS shall be capable of distinguishing same-direction vehicles from other objects, in order to avoid issuing alerts due to objects such as small debris that do not pose crash threats.
b) The IVBSS shall be capable of identifying and tracking the vehicle or vehicles that pose the most potential threat for a rear-end crash.

c) The IVBSS shall be capable of rejecting the vast majority of overhead objects from consideration as potential rear-end threats. Examples of overhead objects include overpasses and overhead signs.

d) The IVBSS shall be capable of rejecting the vast majority of roadside objects from consideration as potential rear-end threats. Examples of roadside objects include road signs and mailboxes.

e) The IVBSS shall be capable of suppressing crash alerts that would be triggered by vehicles that are crossing the subject vehicle's path but will not remain in the subject vehicle's path long enough to become crash threats. (Examples include opposite-direction vehicles making left turns across the host's path and same-direction vehicles on a multiple-lane roadway that are changing lanes from a lane adjacent and to the left of the subject vehicle's travel lane to a lane that is to the right of the subject vehicle's travel lane.)

f) The IVBSS shall consider parked cars alongside the roadway as potential threats for a rear-end crash if the subject vehicle is drifting onto the shoulder.

g) The IVBSS shall be capable of identifying both stopped and moving vehicles as potential threats for a rear-end crash, even those vehicles that have been stopped for a long period of time.

4.2.1.2 Path prediction and target selection

The following address path prediction and target selection:

a) The IVBSS shall be capable of predicting the paths of the subject vehicle as well as principal other vehicles in order to identify the vehicle(s) whose path(s) may intersect with the subject vehicle's path. These vehicle(s) shall be considered in the threat assessment.

b) The system shall not consider crossing traffic and oncoming traffic when assessing rear-end crash threat.

4.2.2 Threat assessment

The rear-end scenario threat assessment shall be a set of computations that determines whether it is appropriate to request that the driver-vehicle interface provide the driver with crash alerts and/or advisories. This request is weighed by the arbitration function in combination with information and requests from the other crash alert functions; the arbitration function is the final decision-maker in displaying information to the driver. (See Section 7 for arbitration requirements.)

4.2.2.1 Crash alert timing

Crash alert timing addresses when the system issues a crash alert for a potential threat. Crash alert timing in rear-end crash scenarios shall allow inattentive drivers enough time that they can react to the crash alert and respond by braking to avoid the rear-end crash (see also the following section).

4.2.2.2 Suppression or delay of crash alerts

There are exceptions to the nominal requirement of section 4.2.2.1, including the following cases:

a) The range to the potential crash threat at the time of a crash alert does not need to exceed the maximum required crash-alert range.

b) The alert may be suppressed or delayed if there is information indicating a likelihood that the subject vehicle or potential-threat vehicle will be maneuvering such that the paths will not intersect. (For example, the onset of a turn signal by the subject vehicle driver may indicate an intention to change lanes, thereby possibly justifying a delay in a crash alert.)

c) The alert may be suppressed or delayed if there is information indicating a likelihood that the subject vehicle or potential-threat vehicle will be maneuvering such that the longitudinal conflict will be reduced. (For example, the onset of a driver brake application may suggest that the driver is aware of the situation and intends to slow in response.)

d) The alert may be suppressed or delayed if there is information that the subject vehicle driver is likely aware of the situation.

e) The alert may be delayed in scenarios where it has been established that a delay is necessary to avoid a substantial increase in false or nuisance alerts. (E.g., earlier research has shown a substantial nuisance alert issue when the subject vehicle is approaching a principal other vehicle that is turning. In order to earn driver acceptance, it may be necessary to delay alerts when this scenario is perceived as possibly existing.)

f) The alert may be delayed or suppressed if there is historical information in the IVBSS that strongly suggests that the current situation is not a true rear-end crash threat and that the crash alert is likely to be a false alarm. (For example, crash alerts addressing rear-end crashes are vulnerable to false alarms due to roadside objects on curves. Historical data may indicate that several alerts have been issued for a stopped object on a particular curve with no subsequent slowing of the subject vehicle. There may be overall benefit in earning driver acceptance if crash alerts for stopped objects are suppressed at this location.)

g) The IVBSS shall not issue a crash alert for a potential rear-end crash event if the braking required to eliminate the developing conflict is modest and within normal braking in those situations.

h) The IVBSS shall not issue a crash alert for a potential rear-end crash event if the subject vehicle is within a travel lane (not straddling a lane boundary) and the principal other vehicle is not within that same travel lane.

i) The IVBSS shall not issue a crash alert for a potential rear-end crash event if the object triggering the crash alert is a stationary object off the roadway and off the improved shoulder. The IVBSS system shall issue crash alerts for potential rear-end crash events when encountering stationary objects such as parked cars on an improved shoulder.

j) The IVBSS shall not issue a crash alert for a potential rear-end crash event if the other vehicle is not traveling in the same direction on the same roadway as the subject vehicle. An example of this is a vehicle on an intersecting road passing in front of the subject vehicle. Another is a vehicle that is part of the oncoming traffic.

k) The IVBSS shall not issue a crash alert if the conditions are not consistent with the domain of applicability or operating conditions described in Section 3.4.

4.2.2.3 Advisories for the rear-end crash threat

The IVBSS may perform computations to support any optional advisories that are provided to the driver to reduce the likelihood that the driver will become involved in a forward-crash conflict. Examples of possible concepts are given in Section 4.3.2.

4.2.2.4 Information about crash-alert circumstances

The threat assessment function shall compute and provide information to the arbitration function to allow arbitration's ability to integrate alert requests and situational information in its function as the final decision-maker on issuing information to the driver.

4.3 Driver-Vehicle Interface Requirements

This section addresses the content of information to be provided to drivers in response to rear-end crash threats. The manner in which the information is presented and integrated with information about road-departure and lane-change/merge threats is treated in Section 8.

4.3.1 Fleet operator and driver controls

The IVBSS may allow the fleet operator and/or the driver to adjust crash alert timing, as long as the minimum performance requirements in Section 4.2 are satisfied for any setting. This flexibility is not required, although most fleets will appreciate the ability to customize the system for their own circumstances.

4.3.2 Informational displays

The IVBSS may provide advisories associated with rear-end crash threats. This may include information about target detection, headway margins, or other relevant information. This is subject to the requirements on the integrated presentation of information that are described in a later section.

4.3.3 Crash alert displays

The IVBSS shall provide crash alerts for potential rear-end crash threats consistent with the requirements in this document. The crash alert shall be designed to prompt the driver to quickly assess or reassess the situation and take any corrective action that may be necessary. The crash alert shall also be designed with the knowledge that there will be false alarms, and that driver acceptance of the IVBSS is a prerequisite to accruing safety benefits.

4.3.4 System status message

The IVBSS shall indicate to the driver when the rear-end crash alert functionality is not available for providing alerts, or is operating at a reduced level of performance such that the performance requirements may not be satisfied. Such situations may occur, for instance, if there is a buildup of ice or slush on a forward-looking sensor, which may lead to a loss of reliable information about the location and paths of potential crash threats.

5 Functional Requirements to Address Road Departure Crashes

This section presents functional requirements for the portion of IVBSS that provides crash alerts and advisories to drivers to assist them in avoiding or reducing the harm associated with drifting off the road.

5.1 Sensing Requirements

This section addresses the collection of data about the subject vehicle, roadway, and other vehicles or nearby obstacles. Section 5.2.1 addresses the combination of the data.

5.1.1 Sensing subject vehicle information and driver control inputs

The following requirements apply:

a) The IVBSS shall obtain data from the subject vehicle and from sensors on the vehicle that are dedicated to the IVBSS in order to support estimates of the following: subject vehicle state, driver inputs to the vehicle controls, and the predicted subject vehicle path. Data may also be obtained to support other computations such as predictions of driver maneuvers.

b) The data to be obtained shall include subject vehicle speed and driver turn signal use.

c) These data may also include the following, among other possibly useful data elements: Brake pedal use, subject vehicle longitudinal acceleration, driver throttle control, wiper state, steering wheel angle, ambient temperature, and headlight state, vehicle yaw rate.

5.1.2 Sensing roadway geometry and characteristics

The IVBSS shall be capable of collecting information to characterize roadway geometry and other attributes as necessary to support situation characterization and threat assessment.

The data to be obtained shall include the following:

- Heading of the vehicle axes relative to the lane,
- Position of the vehicle in the lane,
- Determination of whether the lane edges are road edges, and
- Time rate of change of the lateral position of the vehicle relative to the road edge.

These data may also include the following data, as well as other data not listed here:

- Functional class of the road being traveled upon, as well as the functional classes associated with upcoming branches, and
- Number of lanes of the road being traveled upon.

Sources of this data may include remote sensors, onboard digital maps in conjunction with GPS data, and historical data retained within IVBSS. Additional information about the roadway may be computed with the assistance of subject vehicle and/or target data. It is noted that the current state of technology does not support faultless estimation of the quantities listed above.

5.1.3 Sensing objects and characterizing object type and motion

The IVBSS may use information about nearby vehicles or obstacles to assist in the determination of whether to provide the driver with information about a road departure threat. An example is the possible use of the sensed motion of vehicles ahead of the subject vehicle to give additional clues about the location of a curvature change.

5.1.4 Estimating road condition parameters

The system shall use data from the subject vehicle and/or from dedicated IVBSS sensors to compute parameters addressing whether road conditions may affect the ability of the driver to perform evasive maneuvers. An example is the use of temperature and wipers to detect whether there is a possibility of a slippery road surface.

5.1.5 Sensing driver attributes

The system may use subject vehicle data, roadway data, and target data to determine the value of parameters that characterize aspects of the driver's state. These parameters may be used to adjust the presentation of IVBSS information to the driver, as long as the minimum performance requirements are satisfied. Examples of the use of driver state may be the use of the perception that a driver is fatigued or distracted to increase the sensitivity of crash alert timing.

5.2 **Situation Awareness and Threat Assessment Requirements**

5.2.1 Situation characterization

The system shall integrate vehicle data, target data, roadway data, and road condition data to develop an awareness of the driving situation suitable for making threat assessment decisions.

5.2.1.1 Estimation of roadway geometry and characteristics

The IVBSS may distinguish between the road edge and the edge of a lane that has another same-direction travel lane beyond that.

The IVBSS may obtain information about the road functional class, number of lanes, posted speed, local land use, and other attributes of the roadway in order to improve system performance.

5.2.1.2 Estimation of vehicle position, pose, and path on the roadway

The lateral position of the subject vehicle on the roadway and its pose (orientation) relative to the roadway shall be determined with an accuracy that supports threat assessment.

The path of the subject vehicle relative to the road edge shall be predicted to provide information suitable for assessment of lateral drift crash threat.

5.2.2 Threat assessment

The road-departure threat assessment shall be a set of computations that determines whether it is appropriate to send a request for a crash alert or an advisory to the arbitration module. This request is weighed by the arbitration function in combination with information and requests from the other crash alert functions; the arbitration function is the final decision-maker in displaying information to the driver. (See Section 7 for arbitration requirements.)

5.2.2.1 Computations to support advisories

Advisories may be computed to support appropriate displays to the driver. The advisability of providing such information shall be determined in part by requirements on DVI integration discussed later.

5.2.2.2 Lateral drift over road edges

The IVBSS shall issue a crash alert when the subject vehicle crosses the road edge (with certain allowances for delaying or suppressing alerts per Section 5.2.2.6). Road edge is defined here as the edge of the travel lane that is closest to the road edge. This is not necessarily the edge of the pavement as there is often a drivable shoulder beyond the edge of the outer lane.

There are many situations in which it is common to cross the road edge temporarily and safely, e.g., when drivers “cut corners” in a curve or pass over the lane edge when moving early into a turn lane. The IVBSS must balance the nuisance potential of alerting the driving in these situations against the need for timely alerts when there is an unintended drift over the road edge and only a modest width of shoulder.

The nominal requirement for crash alert timing in lateral drift road-departure scenarios is that the crash alert shall occur no later than when a tire has crossed completely over the edge of the last travel lane on the road.

5.2.2.3 Lateral drift over lane edges that are not road edges

The IVBSS is allowed to issue a crash alert when the subject vehicle crosses a lane edge that is not a road edge. However, the IVBSS shall not issue the alert if the turn signal has been applied by the driver and the adjacent lane is unoccupied.

5.2.2.4 Lateral drift over lane edges

Crash alerts are allowed when a lane edge is crossed for three reasons: (1) to support performance that is consistent with a more intuitive mental model for the driver (lane-edge alerts), (2) to compensate for the small but significant fraction of cases in which the system cannot discern lane edges from road edges, and (3) to more effectively address cases in which a vehicle drifts over several interior lane edges before reaching a road edge, by which time the heading angle may be too great for either the system or the driver to respond effectively.

5.2.2.5 Preemptive lateral drift crash alerts

The IVBSS may provide lateral drift crash alerts significantly before the tire crosses the lane or road edge if there is data to suggest the possibility of running into a fixed object on the roadside. Examples of this include jersey barriers located close to the travel lane in construction zones, drift toward the shoulder on which a parked vehicle is located, or drift toward an adjacent-lane vehicle.

The IVBSS may also provide lateral drift crash alerts significantly before the tire crosses the road edge if a driver has used a sensitivity control to adjust the system in that manner.

5.2.2.6 Suppression or delay of lateral drift crash alerts

There are exceptions to the nominal requirements for issuance of crash alerts at road or lane edges, including the following cases:

a) The IVBSS may suppress or delay a lateral drift alert if there are strong indications that the driver is engaging in an intended maneuver. An example of such an indication is if the rate of the lateral drift increases abruptly from low to high, suggestive of either a deliberate lane-movement maneuver or an error in locating the road edge.

b) The IVBSS may delay a lateral drift alert at a road edge if the system actively senses there is not a fixed object near the road edge and there is likely to be a sizable shoulder.

c) The IVBSS may suppress or delay a lateral drift alert if the subject vehicle is drifting across an interior lane edge and there is no same-direction, adjacent-lane vehicle present.

d) The IVBSS may suppress or delay a lateral drift alert if there is less than full confidence in the location of the road edge.

e) The IVBSS shall suppress a crash alert for a potential lateral drift road departure event if the vehicle is still well within its lane (unless the driver has adjusted a sensitivity setting such that those crash alerts are given quite early). The IVBSS shall suppress a crash alert for a potential lateral drift road departure event if an LDW alert has just been issued and the vehicle has not re-centered in the lane.

f) The IVBSS may suppress a crash alert for a potential lateral drift road departure event if the vehicle is traversing a minor road, such as a neighborhood road, on which lane edges are not likely to be well defined, or on which drivers may commonly wander into the other "lane." An example of logic to achieve this is to suppress lateral drift alerts on roadways using NAVTEQ® digital maps with functional class 5.

g) The IVBSS may suppress lateral drift warning crash alerts if the conditions are not consistent with the domain of applicability or operating conditions described in Section 3.4.

5.2.2.7 Information about crash-alert circumstances

The threat assessment function shall compute and provide information to the arbitration function to allow arbitration's ability to integrate alert requests and situational information in its function as the final decision-maker on issuing information to the driver.

5.3 Driver-Vehicle Interface Requirements

This section addresses the content of information to be provided to drivers in response to road-departure crash threats. The manner in which the information is presented and integrated with information about rear-end and lane-change/merge threats is treated in Section 8.

5.3.1 Fleet operator and driver controls

The IVBSS may allow the fleet operator and/or the driver to adjust crash alert timing, as long as the minimum performance requirements in Section 4.2 are satisfied for any setting. This flexibility is not required, although most fleets will appreciate the ability to customize the system for their own circumstances.

5.3.2 Informational displays

The IVBSS may provide advisories associated with road-departure crash threats. An example may be the display of information about lane-edge tracking confidence. The display of such information is subject to the requirements on the integrated presentation of information that are described in a later section.

5.3.3 Crash alert displays

The IVBSS shall provide crash alerts for potential lateral drift and crash-overspeed crash threats consistent with requirements in this document. The crash alert shall be designed to prompt the driver to quickly assess the situation and take any corrective action that may be necessary. The crash alert shall also be designed with the knowledge that there will be false alarms, and that driver acceptance of the IVBSS is a prerequisite to accruing safety benefits.

5.3.4 System status message

The IVBSS shall indicate to the driver when the road-departure crash alert functionality is not available for providing alerts, or is operating at a reduced level of performance such that the performance requirements may not be satisfied. For instance, a lack of clear lane edges may cause a vision- or laser-based road edge detection system to become unavailable.

6 Functional Requirements to Lane-Change/Merge Crashes

This section presents functional requirements for the portion of IVBSS that provides crash alerts and advisories to drivers to assist them in avoiding or reducing the harm associated with crashes that occur due to lane changes or merging maneuvers by the subject vehicle.

6.1 Sensing Requirements

This section addresses the collection of data about the subject vehicle, roadway, and other vehicles or nearby obstacles. Section 6.2 addresses the combination of the data.

6.1.1 Sensing subject vehicle information and driver control inputs

The IVBSS shall obtain data from the subject vehicle and from sensors on the vehicle that are dedicated to the IVBSS to support estimates of the following: subject vehicle state, driver inputs to the subject vehicle controls, predicted path of the subject vehicle, and position and predicted path of relevant adjacent-lane vehicles. Data may also be obtained to support other computations such as predictions of driver maneuvers.

The data to be obtained shall include subject vehicle speed, yaw rate, and driver turn signal use.

These data may also include the following: brake pedal use, subject vehicle longitudinal and/or lateral acceleration, driver throttle control, and steering wheel angle or angular rate.

6.1.2 Sensing roadway geometry and characteristics

The IVBSS shall be capable of collecting information to characterize the roadway geometry and other attributes to support situation characterization and threat assessment for the lane-change merge-crash alert functionality.

The data to be obtained shall include the following:

- Longitudinal and lateral position of the subject vehicle with respect to the lane edge, and
- Time rates of change of the longitudinal and lateral position of the subject vehicle relative to the lane edge.

The function will be effective if these data are only approximate, since the important problem for heavy truck drivers is the detection of other vehicles, not the accurate estimation of relative motion of an identified vehicle. Additional data may also include the following data, as well as other data not listed here:

- Functional class of the road being traveled upon, and
- Number of travel lanes in the subject vehicle's direction of travel.

Sources of this data may include remote sensors such as radar or vision, onboard digital maps used in conjunction with GPS data, or other approaches. Additional information about the roadway may be computed with the assistance of subject vehicle and/or target data.

6.1.3 Sensing objects and characterizing object type and motion

The IVBSS shall be capable of collecting information to characterize the relative location and motion of vehicles that pose the potential for a lane-change or merging crash. The data shall also support the prediction of whether the paths of the subject vehicle and the other vehicle(s) may intersect.

This information may be obtained in part from remote sensors such as radar or vision in conjunction with other data, such as vehicle motion and roadway information.

6.1.3.1 Identification of potential threats and field of regard

The IVBSS shall be capable of detecting and tracking same-direction vehicles in the field of regard for the lane-change/merge system. The field of regard shall include the travel lanes adjacent to those in which the subject vehicle is traveling. The front edge of the field of regard shall be slightly forward of the subject vehicle and the rear edge shall be a distance behind the subject vehicle and trailer that allows for addressing crashes in which adjacent-lane traffic is overtaking the subject vehicle.

Requirements about the field of regard shall be satisfied for straight roads as well as roads with curves that satisfy those given in Section 3.

6.1.3.2 Object motion

Regarding those vehicles that may pose a lane-change or merge-crash risk, the IVBSS shall determine their position relative to the subject vehicle, laterally and longitudinally, as well as the relative speed in both the lateral and longitudinal directions.

6.1.4 Estimating road condition parameters

The system may use data from the subject vehicle and/or from dedicated IVBSS sensors to compute parameters addressing whether road conditions may affect the ability of the driver to perform evasive maneuvers.

6.1.5 Sensing driver attributes

The system may use subject vehicle data, roadway data, and target data to determine the value of parameters that characterize aspects of the driver's state. These parameters may be used to adjust the presentation of IVBSS information to the driver, as long as the minimum performance requirements are satisfied.

6.2 Situation Awareness and Threat Assessment Requirements

6.2.1 Situation characterization

The system shall integrate vehicle data, target data, roadway data, and road condition data to develop an awareness of the driving situation that is sufficient for making threat assessment decisions.

6.2.1.1 Path prediction and identification of a threat

The IVBSS shall be capable of projecting the paths of the subject vehicle and adjacent-lane vehicles within the field of regard to determine whether and when they may intersect. The IVBSS shall consider a nearby vehicle a potential threat if those paths intersect in the near future.

6.2.2 Threat assessment

The lane-change and merge threat assessment shall be a set of computations that determines whether it is appropriate to send a request for a crash alert or advisories to the arbitration module. This request is weighed by the arbitration function in combination with information and requests from the other crash alert functions; the arbitration function is the final decision-maker in displaying information to the driver. (See Section 7 for arbitration requirements.)

6.2.2.1 Computations to support advisories

Advisories shall be computed and displayed to the driver when an adjacent-lane, same-direction vehicle is within or near a driver's blind spot. Additional information is allowed, although the advisability of providing such information shall be determined in part by requirements on DVI integration discussed later.

6.2.2.2 Crash alert timing

The lane-change/merge-crash alert timing shall issue a crash alert in time for the subject vehicle driver to react and respond with moderate authority to avoid a crash.

6.2.2.2.1 Suppression or delay of lane-change or merge crash alerts

There are exceptions to crash alert timing requirement above, including the following cases:

a) The IVBSS may delay a crash alert for a potential lane-change crash event if there is evidence that the driver is aware of the adjacent-lane vehicle.

b) The IVBSS shall not issue a crash alert for a potential lane-change crash event if the other vehicle is not predicted to be occupying or nearly occupying the same space as the subject vehicle in the near future. Two cases that may be considered here:

    1. The other vehicle is traveling in an adjacent lane at a speed similar to the subject vehicle's speed and is not occupying space adjacent or nearly adjacent to the subject vehicle. (An example is when the front of the other vehicle is behind the rear of the subject vehicle.)

    2. The other vehicle is in an adjacent lane and overtaking the subject vehicle, and is at a sufficiently long distance behind the subject that the other vehicle's driver may be expected to observe the conflict, respond reasonably promptly with modest braking, and avoid any impact.

c) The IVBSS may suppress a crash alert for a potential lane-change crash event if the conditions are not consistent with the domain of applicability or operating conditions described in Section 3.4.

d) The IVBSS shall suppress a warning for opposing traffic detected from the side the warning was issued.

e) The IVBSS shall suppress a warning for stationary roadside objects (including stationary vehicles) detected from the side the warning was a issued.

6.2.2.3 Information about crash alert circumstances

The threat assessment function shall compute and provide information to the arbitration function to allow arbitration's ability to integrate alert requests and situational information in its function as the final decision-maker on issuing information to the driver.

6.3 **Driver-Vehicle Interface Requirements**

This section addresses the content of information to be provided to drivers in response to lane-change/merge crash threats. The manner in which the information is presented and integrated with information about rear-end and road-departure threats is treated in Section 8.

6.3.1 Fleet operator and driver controls

The IVBSS may allow the fleet operator and/or the driver to adjust crash alert timing, as long as the minimum performance requirements in Section 4.2 are satisfied for any setting. This flexibility is not required, although most fleets will appreciate the ability to customize the system for their own circumstances.

6.3.2 Informational displays

The IVBSS shall provide advisories associated with lane-change and merge crash threats. The IVBSS shall provide an indication if an adjacent-lane vehicle is within or near a possible blind spot. The display of such information is subject to the requirements on the integrated presentation of information that are described in a later section.

6.3.3 Crash alert displays

The IVBSS shall provide crash alerts when the subject vehicle is initiating a signaled or un-signaled lane change maneuver while there is an adjacent-lane, same-direction vehicle that is a potential crash threat.

The crash alert shall be designed to prompt the driver to quickly assess the situation and take any corrective action that may be necessary.

6.3.4 System status message

The IVBSS shall indicate to the driver when the crash alert functionality is not available for providing alerts, or is operating at a reduced level of performance such that the performance requirements may not be satisfied.

7 Functional Requirements to Address Crashes in Multiple-Threat Scenarios

The arbitration function shall identify when there is more than one type of potential crash threat, and allow only one crash alert to be presented to the driver. The arbitration function shall select the crash alert as the one most likely to evoke the most helpful driver response.

7.1 Inputs to Arbitration

Arbitration uses data provided by the three crash alert functionalities that address rear-end, road-departure, and lane-change/merge crash scenarios. Two definitions are useful in describing the required input data.

The time to critical event is the estimated time to a rear-end collision, road-edge or lane-edge crossing, or the time to the lane-change/merge collision.

Maneuvering room is the distance to the nearest object posing a potential crash risk.

The data for arbitration shall include:

- The threat severity and confidence for each crash type,
- The timing between sequential crash events,
- Information that the subject vehicle driver is likely aware of a particular crash type occurring in a multiple threat scenario,
- Time to the critical event for each crash type (and the confidence of that estimate),
- Estimate of the lateral maneuvering room to the side of the vehicle,
- Forward maneuvering room,
- Road geometry, and
- Time to the next expected alert for each crash type.

7.2 Determine Precedence of Threats

When multiple threats exist, the IVBSS shall determine the precedence of the threats and select the most critical threat.

7.3 Determine the Information to Provide to the Driver

The system shall determine and then present the DVI crash alert and/or advisories that are most likely to direct the driver's attention to the most critical threat.

8 Integrated Driver-Vehicle Interface

This section addresses the need to provide the driver with an intuitive and integrated interface with the IVBSS. There are four subsections: driver controls, advisories, crash alerts, and system status messages. Several requirements addressing the interface are described in Sections 3, 4, 5, 6, and 7.

8.1 Fleet Operator and Driver Controls

Control inputs to the IVBSS are not required; however, there are allowances for the system to have any combination of the four types of driver input below. Note that these controls may be offered to fleet operators and/or drivers. Many fleets, of course, may choose to establish some or all of these settings for their fleet and not offer drivers the ability to alter those settings. The allowed inputs are:

a) Adjustable settings to adjust crash alert timing within a limited range,
b) Adjustable settings to control aspects of the timing and/or display of advisories,
c) A temporary mute control that allows the driver to temporarily suppress IVBSS crash alerts and/or advisories for a short period of time, and
d) A volume control for the audible alerts.

For those driver inputs that are included, the IVBSS shall accept driver input from dedicated buttons and/or switches and provide an indication to the driver of the state of those inputs within the system.

No matter the state of the adjustable sensitivity input, the IVBSS must meet the performance requirements in this document.

The driver shall not be allowed to disable the system for more than a few minutes at a time.

The volume control shall not allow the driver to reduce the volume of the audible crash alert components to a level that is not distinguishable in the presence of cabin noise and radio volumes.

8.2 Advisories

The IVBSS shall indicate that an adjacent-lane vehicle is in the subject vehicle driver's blind spot.

The IVBSS shall provide information about the relative location of preceding vehicles, e.g., cues related to time headway. Since heavy trucks have limited braking capability, especially in loaded conditions, the system shall assist drivers in maintaining appropriate following distances.

The IVBSS may also present advisories to assist the driver in maintaining proper margins of safety and to help prevent a conflict from developing. Examples of possibly appropriate advisories include additional indications of adjacent-lane traffic, such as cues about fast-approaching vehicles.

Other advisories may be useful as well.

8.3 Crash Alert Displays

The manner in which IVBSS provides crash alerts shall meet the following requirements:

8.3.1 Purpose of crash alert displays

The crash alert shall prompt an unaware driver to adjust attention in a manner that immediately allows assessing the appropriate aspect of the driving situation.

The crash alert displays must balance the need to elicit timely driver responses in situations with actual crash potential with the need to minimize nuisance effects so as to achieve driver acceptance

8.3.2 Qualities of crash alert displays

This section describes qualities that are important in an integrated crash warning system. The following section describes the requirements for the displays for the IVBSS. The displays of the IVBSS crash alerts shall satisfy the following:

a) Only one crash alert shall be presented to the driver at a time. For example, an LDW alert and an FCW alert cannot be presented simultaneously on the heavy truck platform.

b) The crash alert displays shall have sufficient duration to allow the driver to recognize the type of each crash alert.

c) All crash alert displays shall use auditory modalities.

d) All crash alerts shall have an accompanying visual component that serves as confirmation for the driver about the type of crash alert that has occurred. The visual component shall not necessarily be presented simultaneously with the auditory cues. This visual component shall remain visible for sufficient duration to allow the driver some discretion about how soon to consult the visual element.

e) Audible crash alerts shall be heard over cabin noises, including when the radio is playing at levels less than “very loud.”

f) The crash alert tones, and/or visual displays associated with each crash alert type shall be distinguishable by the driver from displays associated with other crash alert types. The displays shall also be distinguishable from other non-IVBSS vehicle tones, or visuals (e.g., the FCW tone must not be the same as the LDW tone or the tone for an unfastened seat belt).

g) Crash alerts for LDW and LCM shall be laterally directional (right and left).
   - The lateral drift crash alerts shall be issued on the same side as the drift (e.g., a left drift would elicit an auditory crash alert that emanates from the left IVBSS speaker).
   - The lane-change/merge crash alerts shall be issued on the same side as the lane change or merge (e.g., a left lane change would elicit an auditory crash alert that emanates from the left IVBSS speaker).

h) Crash alerts for FCW shall not be directional from drivers' standpoint (i.e., from left or right side).

8.4 IVBSS Crash Alert and Advisory Displays

Based on the desired qualities above as well as other information, a set of requirements for the display modalities for each type of alert and display is shown in Table 7.

Table 7. Crash alert and advisory modalities for the heavy truck platform

Crash Type	Crash Alert Modalities	Advisory Modalities
Rear-end crash	Audible and visual	Audible and visual
Lateral drift	Audible and visual	None
Lane-change and merging	Audible and visual	Visual

8.5 System Status Information

System status information shall be presented using visual and/or auditory cues. Haptic cues shall not be used for system status information.

System status information shall be provided to the driver as follows:

a) The IVBSS system shall inform the driver of the system state, including availability of the crash alert functionalities (as defined in Section 3.5.3). This shall be continuously indicated.

b) The IVBSS shall inform the driver if the performance of the IVBSS is reduced enough that it is likely that these functional requirements will not be met.

c) The IVBSS system shall inform the driver of the selected set of sensitivity levels for the crash alerts if the sensitivity is adjustable by the driver. The sensitivity levels shall be presented to the driver visually at a minimum on change and at vehicle/system start-up.

d) The switches that allow the driver to select crash alert sensitivity shall provide tactile feedback to the driver to indicate setting.

e) The IVBSS system shall indicate the selected volume for the audible crash alerts upon change of a driver-adjustable setting, and upon startup. If the driver cannot adjust the volume, no indication is necessary.

f) All IVBSS system status messages shall be unique and shall have minimum durations that allow the driver to recognize the information.

9 System Management Functions

The system shall monitor the health and status of all internal IVBSS activities, in order to provide the driver with information that expresses the system state (as enumerated in Section 3.5.3).

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