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**Functional Requirements**  
**For Integrated Vehicle-Based Safety Systems**  
**(IVBSS) - Light Vehicle Platform**

*Prepared by*

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

*for*

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

March 28, 2008

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16. Abstract <p>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.</p> <p>This document proposes functional requirements for the system to be developed and field-tested on the light vehicle 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 light vehicle platform encompasses passenger vehicles including sedans, sport-utility vehicles, light trucks, minivans, and vans. The IVBSS on the light vehicle platform addresses the following crash types:</p> <ul style="list-style-type: none"> <li>• Road departures due to unintended lateral drift,</li> <li>• Road departures due to travel through curves at excessive speeds,</li> <li>• Rear-end crashes, and</li> <li>• Lane-change and merge crashes due to unsafe lane movements.</li> </ul>					
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### Acronyms

CSW	Curve-speed warning
FCW	Forward crash warning
IVBSS	Integrated vehicle-based safety system
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

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### 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.



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**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.

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### 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 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 Traffic 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 crash alerts and advisories to enhance the driver's awareness of the driving situation. This document describes functional requirements for the system to be field-tested on the light vehicle platform. These requirements are generated solely for the system created within this project, and are not intended to be prescriptive for integrated crash warning systems developed outside the project. The light vehicle platform encompasses passenger vehicles including sedans, sport-utility vehicles, light trucks, minivans, and vans. A companion report addresses functional requirements for the heavy truck 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 is designed for a heavy truck platform and that is also called IVBSS in that platform's documents. The IVBSS on the light vehicle platform addresses the following crash types:

- Road departures due to unintended lateral drift,
- Road departures due to travel through curves at excessive speeds,
- Rear-end crashes, and
- Lane-change and merge crashes due to unsafe lane movements.

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

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(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, and
- Sharing approaches, technology, and insights between the light vehicle and heavy truck teams.

The requirements for the light vehicle platform differ somewhat from those developed for the heavy truck 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 considered similar issues and pursued substantially different approaches only when it was clear that platform-related considerations warranted 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 will 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.

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## 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 et al., 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 do-not-warn scenarios that are relevant to these functional requirements for IVBSS.

### 2.1 Rear-End Crash Scenarios

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

- Subject vehicle: The vehicle equipped with the IVBSS.
- Principal other vehicle: The 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.

Table 1 is derived from an analysis of crash data from the 2003 General Estimates System (GES) that was performed by the Volpe Center for NHTSA (Najm, et. al, 2007). The table indicates those rear-end scenarios that will be considered the primary scenarios for the IVBSS requirements. The first three scenarios address situations in which the subject vehicle is not attempting a maneuver (e.g., a passing maneuver), and approaches a principal other vehicle from behind. The three scenarios are distinguished from one another by the speed and deceleration of the principal other vehicle. The fourth scenario, denoted RES-4 (for “rear-end scenario number four”), is associated with cases in which

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the subject vehicle is attempting a maneuver, and strikes the rear end of the principal other vehicle.

The table shows that these highlighted scenarios were associated with 1,371,000 police-reported crashes in 2003, which represented 92.3% of all light vehicle rear-end crashes. The most common conditions associated with rear-end crashes are daylight, dry pavement, and a straight road. (See Najm, et. al 2007 for details.)

Table 1. Rear-end crash scenarios for the IVBSS and their relative frequency for the light vehicle platform

Index	Scenario Description	Frequency	Percent
1	Principal other vehicle is stopped	746,000	50.4%
2	Principal other vehicle is decelerating	347,000	23.4%
3	Principal other vehicle is moving at constant speed	200,000	13.5%
4	Principal other vehicle is following and making a maneuver	75,000	5.1%
--	Other scenarios not considered primary scenarios	114,000	7.7%
	Total	1,483,000	100.0%

Previous studies indicate that the majority of rear-end crashes are associated with driver distraction or driver inattention (Kiefer et al, 1999). Therefore, 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

Table 2 presents the primary road-departure crash scenarios to be addressed by IVBSS, per Najm et al., 2007. Two common types of road-departure crashes are represented:

- Lateral drift crashes (scenario RDS-1 and some of scenario RDS-4 in Table 2)
- Crashes that occur in curves (scenario RDS-2, especially, as well as scenario RDS-3). Curve-related crashes are often related to speeding.

Together these targeted scenarios account for 614,000 police-reported crashes, or 60% of all road-departure crashes involving light vehicles.

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Table 2. Road-departure crash scenarios for the IVBSS and their relative frequency for the light vehicle platform

Index	Scenario Description	Frequency	Percent
1	Subject vehicle is going straight and departs road edge	261,000	25.4%
2	Host vehicle is negotiating curve and loses control	172,000	16.8%
3	Subject vehicle is negotiating curve and departs road edge	116,000	11.3%
4	Subject vehicle is initiating a maneuver and departs road edge	65,000	6.3%
--	Other scenarios not considered primary scenarios	414,000	40.2%
	Total	1,028,000	100.0%

### 2.3 Lane-Change Crash Scenarios

Table 3 presents the primary lane-change and merging crash scenarios to be addressed by IVBSS, per Najm et al., 2007. Three types of crashes are represented here:

- The most common crash type is unsafe lane changes by the subject vehicle that result in crashes with adjacent vehicles (scenarios LCMS-1 and LCMS-4). This accounts for 49% of all lane-change and merging crashes.
- Turns by the subject vehicle that result in crashes with adjacent vehicles are less common (scenario LCMS-2).
- Merges by the subject vehicle resulting in a crash with an adjacent vehicle (scenario LCMS-5) occur much less frequently than the other scenarios, accounting for only 4.3% of all lane-change or merging crashes.

Together these targeted scenarios account for 427,000 police-reported crashes, or 79% of all road-departure crashes involving light vehicles.

Table 3. Lane-change and merge crash scenarios for the IVBSS and their relative frequency for the light vehicle platform

Index	Scenario Description	Frequency	Percent
1	Subject vehicle changes lanes and encroaches on adjacent vehicle	211,000	38.8%
2	Subject vehicle turns and encroaches on adjacent vehicle	74,000	13.6%
-3	Subject vehicle drifts and encroaches on adjacent vehicle	64,000	11.8%
4	Subject vehicle changes lanes or passes – misc.	55,000	10.1%
5	Subject vehicle merges and encroaches on adjacent vehicle	23,000	4.3%
--	Other scenarios not considered primary scenarios	117,000	21.4%
	Total	544,000	100.0%

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### 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 are shown in Table 4, with illustrations of each following in Figure 1.

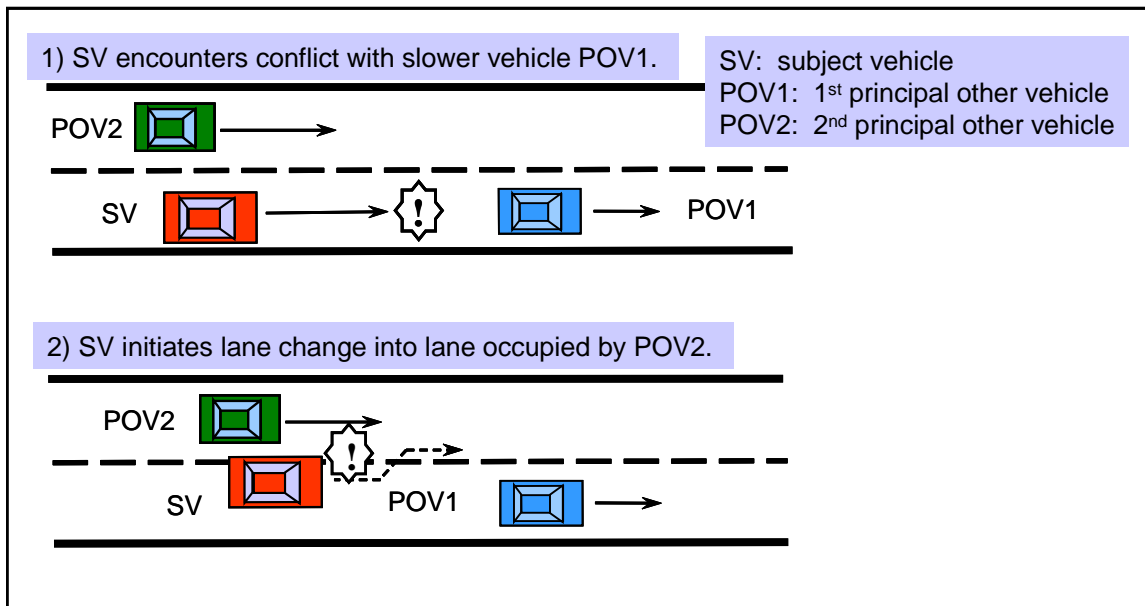
Table 4. Multiple-threat crash scenarios for the IVBSS light vehicle platform

Index	Scenario Description
1	Subject vehicle approaches a slower vehicle ahead and initiates a lane change into an occupied lane.
2	Subject vehicle initiates lane change into occupied adjacent lane occupied by same-direction vehicle. To avoid the conflict, the subject vehicle aborts lane change and returns to original lane of travel but encounters a slowing vehicle ahead.
--	Other scenarios that the project team does not consider to be primary scenarios.

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### Scenario 1



### Scenario 2

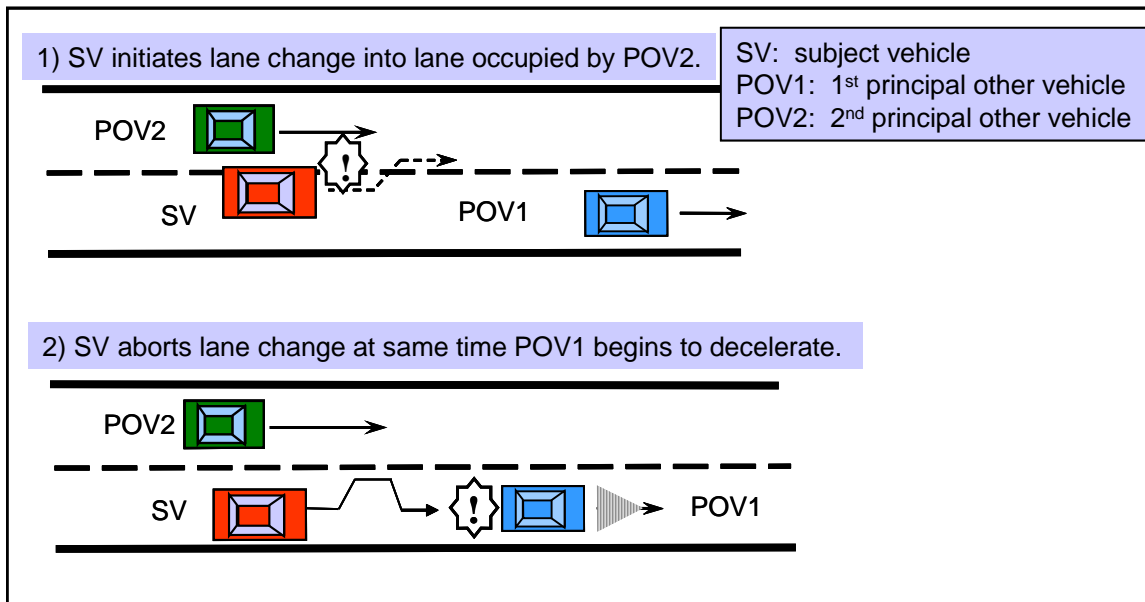


Figure 1. Two multiple-threat scenarios



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### 2.5 Do-Not-Warn Scenarios

In order to achieve sufficient driver acceptance of the IVBSS and to enhance system effectiveness, the IVBSS must avoid issuing an excessive number of alerts in situations that 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, 2007). Table 5 shows examples of false alarms and nuisance alerts.

The do-not-warn scenarios are detailed in the IVBSS Light Vehicle Verification Test Plan document (Husain, 2008).

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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 is traveling in middle lane of a freeway and will soon pass by an exit ramp.	Road departure (curve-overspeed)	False (if alert triggered by curve on ramp)
Subject vehicle is passing through an area where onboard map accuracy is not sufficient for this application.	Road departure (curve-overspeed)	False (road geometry estimate is not accurate enough)
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 approaching a familiar curve on dry pavement.	Road departure (curve-overspeed)	Nuisance (alert is not appreciated)
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)

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### 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 driver acceptance of the system 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) Curve-overspeed road-departure crashes in which the subject vehicle leaves the roadway due to excessive speed in a curve
- d) Lane-change crashes in which the subject vehicle changes lanes and collides with another vehicle moving in the same direction
- e) 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 (all but one are optional).

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### 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 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 8.4.

## **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 goal of 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 the crash. 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. In rare cases, the alerts may be suppressed altogether if the scenario is not a primary scenario (as described in Section 2) and the number of nuisance alerts may be excessive.

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.

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### 3.2.2.2 Use of vehicle control in IVBSS

The IVBSS shall not provide automatic control of the vehicle, other than minor perturbations of vehicle motion as a consequence of a crash alert presentation (e.g., a brake pulse which slows the vehicle slightly).

This statement addresses the scope of the IVBSS and the requirements in this document, and is not meant to prohibit 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*

The IVBSS shall have four 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 Road departure warning

Road departure warning 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 two functions:

- Lateral drift warning, which 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 v 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.
- Curve speed warning, which 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.

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### 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

Arbitration provides information to assist the driver in avoiding or reducing the severity of crashes when the driving scenario involves multiple crash threats.

## **3.3.2 Achieving IVBSS functionality**

The IVBSS is defined as the sum of elements that are not already part of a vehicle but are necessary to deliver the IVBSS function. 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). In turn, the IVBSS may issue commands to vehicle systems (e.g., a brake pulse may be incorporated as a cue to the driver).
- 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 Sections 4 through 7.

### 3.3.2.2 Major functional activities within the IVBSS

The IVBSS shall include four major activities, which are 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

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(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 (represented by element 2 in Figure 3). This will be described in more detail in Sections 4, 5, and 6.
3. Presentation of crash-avoidance 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 the 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 described in Section 9.

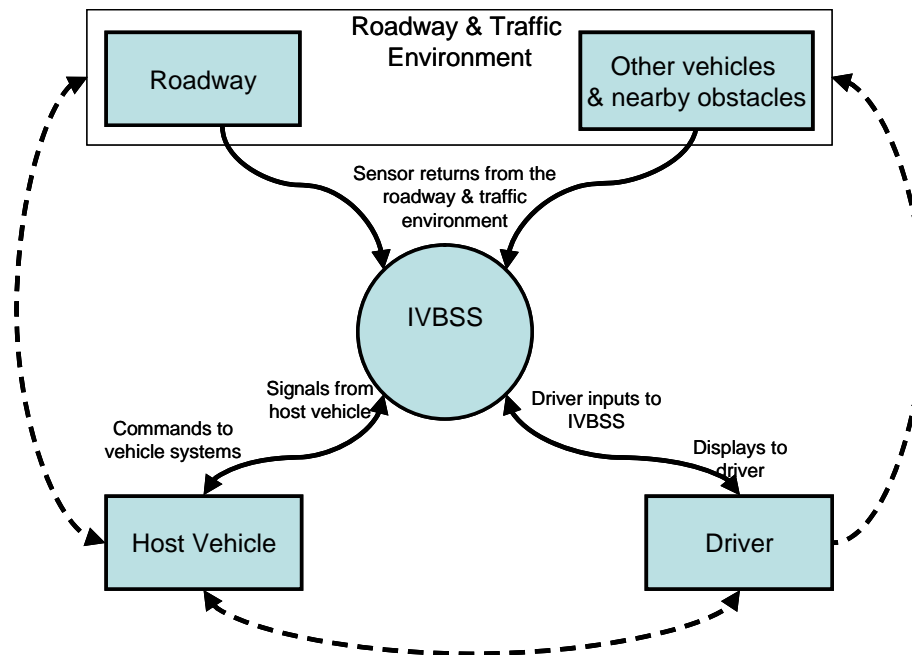


Figure 2. Interaction of the IVBSS with external elements

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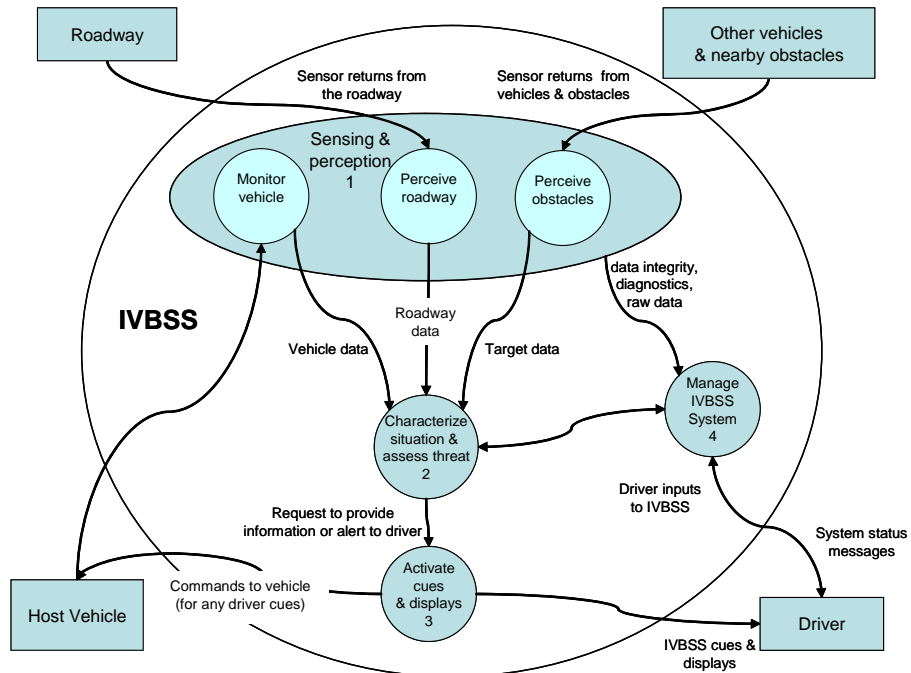


Figure shows only the interactions directly with or within IVBSS.

Figure 3. Key functional elements within the IVBSS

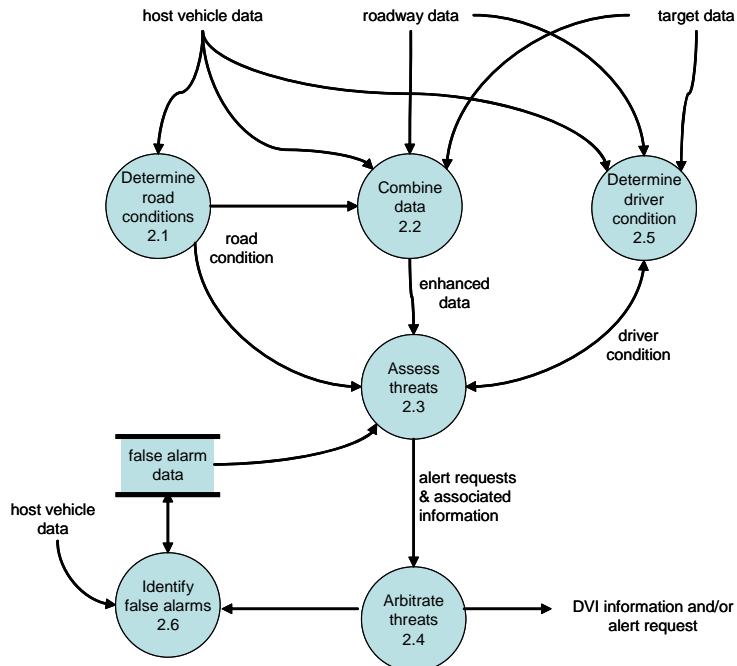


Figure 4. Elements within situation identification and threat assessment



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### 3.4 Domain of Applicability of Requirements

#### 3.4.1 *Subject vehicle characteristics*

The IVBSS for the light vehicle platform shall operate as indicated herein when installed on a light vehicle, as described in Section 1. Other types of subject vehicles have not been explicitly considered in the development of these requirements, though many or all of the requirements may indeed be applicable.

#### 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, but may be satisfied, when traveling on other roadways or surfaces, such as private roads, driveways, parking lots, and unpaved roads.

##### 3.4.2.2 Exempted roadway geometries

Exceptions to the requirement of Section 3.4.2 are allowed as follows. The IVBSS or some of its alert functionalities may become unavailable to provide crash alerts or advisories 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 similar-sized 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

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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 light vehicle platform, this minimum operating speed shall be the same for all types of crash alerts.
- 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

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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 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) Crash alerts from one system (e.g., FCW) may become unavailable while other crash alerts (e.g., LDW) are available.
- c) If the arbitration function becomes unavailable (due to hardware or software faults, for instance), the entire IVBSS shall become non-operational.

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### 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 do appear in other sections of 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., loss of GPS,
- 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 sensing 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 reduction in performance is in effect.

### 3.5.3 System states

The table below shows system states of the IVBSS.

Table 6. System state possibilities of the IVBSS

<b>IVBSS System State Possibilities</b>
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.

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## 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 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 IVBSS shall also obtain data from the subject vehicle that are needed for other computations, such as the estimation of other vehicles' motions.
- c) 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.

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- 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 characterizing objects that are sensed as possible principal other vehicles (same-direction vehicles or stopped vehicles that may pose a potential crash risk) and other non-vehicle objects. This is needed to support later discrimination between potential rear-end crash threats and other objects.

#### **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, relative speed, and whether the principal other vehicle is braking.

#### **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

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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.

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## 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.
- 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 addresses 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.



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- 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.

#### **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. For example, a substantial challenge in reducing nuisance alerts occurs when the subject vehicle is approaching a principal other vehicle that is turning. In order to earn driver

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acceptance, it may be necessary to delay alerts when this scenario is perceived as a possibility.

- 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 in its function as the final decision-maker on issuing information to the driver.

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### **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 Driver controls**

The IVBSS may allow the driver to adjust crash alert timing, as long as the minimum performance requirements in Section 4.2 are satisfied for any setting.

#### **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.

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## 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 lateral drift and curve-overspeed crashes.

### 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 IVBSS shall also obtain data from the subject vehicle that are needed for other computations. An example is the use of speed and yaw rate in conjunction with a digital map to locate the subject vehicle on the road network.
- c) The data to be obtained shall include subject vehicle speed, yaw rate, and driver turn signal use.
- d) 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.

#### 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,
- Road curvature,
- Upcoming road curvature,

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- Time rate of change of the lateral position of the vehicle relative to the road edge, and
- Presence of upcoming roadway branches, and the road geometry on those branches.

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 or a branching point.

### ***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.

Slippery roads may affect the driver's ability to negotiate a curve enough to adjust the crash alert timing or the advisories. Parameter values are required by threat assessment to incorporate this effect.

### ***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

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may be the use of the perception that a driver is fatigued or distracted to increase the 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 Prediction of most-likely roadway

The IVBSS shall make predictions of whether the subject vehicle is likely to branch onto an upcoming roadway, in order to support the assessment of road-departure crash threats involving over-speeding on curves on those branches. The most-likely roadway is either the roadway being traveled by the subject vehicle or an upcoming branch that the subject vehicle is expected to move onto.

#### 5.2.1.2 Estimation of roadway geometry and characteristics

The IVBSS shall compute the curvature of the most-likely roadway as a function of distance down road, in order to support threat assessment for potential lateral-drift and curve-overspeed crash threats. This estimate shall address the portion of the roadway from the current location to a point down-range far enough to support timely alerts that allow the driver to react and respond safely.

The IVBSS shall estimate upcoming road curvature and the anticipated lateral acceleration in the curve at the current speed (or a speed that is projected to the time at which the vehicle will be in the curve).

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, advisory signage, local land use, and other attributes of the roadway in order to improve system performance.

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### 5.2.1.3 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 Crash alerts: Lateral drift road-departure scenarios

##### 5.2.2.2.1 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 5.2.2.2.4). 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.

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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. However, the IVBSS shall not issue the alert if the turn signal has been applied by the driver.

### 5.2.2.2.2 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 an alert targeted toward road departure avoidance if the turn signal has been applied by the driver. (Alerts for other reasons, such as lane-change merges, may be applicable, however.)

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.

### 5.2.2.2.3 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 an IVBSS control to adjust the system in that manner.

### 5.2.2.2.4 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



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- 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 preference 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.

### 5.2.2.3 Crash alerts: Curve-overspeed scenario

The following functional requirements apply to the curve-speed warning function:

- a) The IVBSS shall issue crash alerts when the anticipated lateral acceleration in an upcoming curve exceeds a threshold level. This threshold shall be significantly below the tire-road friction limits associated with dry pavement. (Most crashes associated with speeding in curves are not caused by speeds being so high that friction loss is inevitable.) The threshold may vary with road type or other meaningful factors.
- b) The IVBSS shall consider curves on upcoming road branches when assessing the potential threat of a curve-overspeed crash. An example of a road branch is an upcoming exit ramp when the subject vehicle is traveling on a freeway.
- c) The threat assessment shall adjust its crash alert timing to provide earlier alerts when there is evidence that the road condition may be slippery.

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### 5.2.2.3.1 Suppression or delay of curve-speed crash alerts

There are exceptions to this nominal requirement, including the following cases:

- a) The IVBSS shall not issue a crash alert for a potential curve-overspeed road departure event if the level of driver braking required to slow the vehicle to the maximum safe speed is modest and within normal levels of braking in those situations.
- b) The IVBSS may use different threshold levels for lateral acceleration for curves that are on an upcoming road branch, versus the threshold used on curves on the road already being traveled.
- c) The IVBSS may suppress or delay a crash alert for the curve-overspeed scenarios if there is an indication that the driver is braking or intends to soon begin slowing the vehicle (e.g., a throttle release may suggest the driver is preparing to coast or brake to reduce speed).
- d) The IVBSS may suppress all crash alerts for the curve-overspeed scenarios on very short radius curves often associated with U-turns or similar special roadway features.
- e) The IVBSS shall issue a crash alert for a potential curve-overspeed road departure event that is associated with an upcoming branch only if there is strong evidence that the vehicle will indeed take the branch.
- f) The IVBSS may suppress or adjust crash alert timing for crash alerts when the subject vehicle is approaching a curve that results in a small change in heading angle.
- g) The IVBSS may suppress or delay crash alerts if there is historical data that shows that previous alerts in that location were provided without any apparent crash risk.

### 5.2.2.4 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 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 Driver controls**

The IVBSS may allow the driver to adjust crash alert timing, as long as the minimum performance requirements are satisfied for any setting.

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### **5.3.2 Informational displays**

The IVBSS may provide advisories associated with road-departure crash threats. An example of this may be the display of information about safe speeds for upcoming curves. 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. Examples of reasons for an unavailable system include a loss of GPS for a system that uses digital maps as primary sensors (such as for the curve-speed warnings) or a lack of clear lane edges for a vision- or laser-based road edge detection system.

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## 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:

- Heading of the lane relative to the vehicle axes,
- Road curvature,
- Lateral position of the subject vehicle with respect to the lane edge, and
- Time rate of change of the lateral position of the vehicle relative to the lane edge.

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

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- 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 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.

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### **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.

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### 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 delay a crash alert for a potential lane-change crash event if the position of the subject vehicle in the lane is nominally in the center of the lane or towards the opposite direction of the threat.
- d) The IVBSS may delay a crash alert for a potential lane-change crash event if the vehicle dynamics suggest that the driver is not intending to move towards the threat.
- e) 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.

### 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 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

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integrated with information about rear-end and road-departure threats is treated in Section 8.

### **6.3.1 Driver controls**

The IVBSS may allow the driver to adjust crash alert timing, as long as the minimum performance requirements are satisfied for any setting.

### **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.



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## **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 decide which crash alert(s) to display to the driver.

### **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.

### **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. No more than two crash alerts of a different type may be presented to the driver for any multiple-threat scenario. Only one crash alert of the same type may be presented to the driver, even if it recurs within a multiple-threat scenario.

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## 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 Driver Controls

Driver control inputs to the IVBSS are not required; however, there are allowances for the system to have any combination of four types of driver input:

- a) Driver-adjustable settings to adjust crash alert timing within a limited range,
- b) Driver-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 driver volume control for the audible alerts.

For those 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 driver preference 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 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:

- a) The IVBSS may indicate a safe travel speed for an upcoming curve,

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- b) The IVBSS may provide information about the relative location of preceding vehicles, e.g., visual icon(s) related to time headway, and
- c) The IVBSS is also allowed to indicate that an adjacent-lane, same-direction vehicle is approaching.

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. For example, a crash alert issued in response to a potential road-edge lateral drift may induce a distracted driver to look at the forward road scene, which allows assessing the risk of road departure and making any necessary corrections.

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) Each type of crash alert shall have only one set of DVI displays. For example, every FCW alert shall be presented with the same set of cues. There shall not be two or more stages to any alert.
- b) 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.
- c) The duration of the crash alert displays shall be sufficient to allow the driver to recognize the type of each crash alert. There shall be a minimum duration.
- d) All crash alert displays shall use auditory and/or haptic modalities.
- e) 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. This shall not necessarily be presented simultaneously with the auditory and/or haptic cues. This visual component shall remain visible for several seconds to allow the driver some discretion about how soon to consult the visual element.

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- f) Audible crash alerts shall be heard over cabin noises, including when the radio is playing at levels less than “very loud.”
- g) The crash alert tones, haptic cues, 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, cues, or visuals (e.g., the FCW tone must not be the same as the LDW tone or the tone for an unfastened seat belt).
- h) For any alert display involving both auditory and haptic displays, those displays shall be presented simultaneously.
- i) Crash alerts for LDW and LCM shall be directional laterally (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 and/or a haptic crash alert on the left set of motors).
  - 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 and/or a haptic crash alert on the left set of motors).
- j) Crash alerts for FCW and CSW shall not be laterally directional.
- k) Crash alert presentations for lateral drifts toward an object and lane-change/merge alerts shall be similar if not identical as both situations require the same driver action and address similar types of threats.

### 8.3.3 IVBSS crash alert displays

Based on the desired qualities above as well as other information, a set of requirements for the displays for each type of alert is shown in Table 7. The contents of this table are pending the results of ongoing research and may be updated in the final functional requirement report to be delivered at the end of Phase 1.

Table 7. Crash alerts displays for the light vehicle platform

Crash Alert Type	Auditory Display?	Haptic Display?
FCW	Yes	Brake pulse
CSW	Yes (same as FCW)	Optional brake pulse same as FCW
LDW – dashed boundary with no adjacent-lane threat	No	Haptic vibration in seat
LDW – solid boundary or dashed with adjacent-lane threat	Yes (but different from FCW and CSW)	None
LCM	Yes (same as LDW)	None

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### 8.4 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 the performance requirements in this document are not met.
- c) The IVBSS system shall inform the driver of the selected set of preference levels for the crash alert timing. The preference 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 timing 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 that driver-adjustable setting, and upon startup.
- f) All IVBSS system status messages shall be unique and shall have minimum durations that allow the driver to recognize the information.

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## 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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## 10 References

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