Connected Commercial Vehicles—Retrofit Safety Device Kit Project

Safety Applications and Development Plan

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16. Abstract

Connected vehicle wireless data communications can enable safety applications that may reduce injuries and fatalities. Cooperative vehicle-to-vehicle (V2V) safety applications will be effective only if a high fraction of vehicles are equipped. Deployment of V2V technology will be enhanced if it is available not only for manufacturing in new vehicles but also for retrofit to existing vehicles. The objective of the Connected Commercial Vehicles—Retrofit Safety Device (CCV-RSD) Kit Project was to develop complete hardware and software that can be used in various brands and models of heavy trucks. The RSD kits provide the functionality needed for cooperative V2V and vehicle-to-infrastructure (V2I) safety applications to support the Model Deployment and other USDOT connected vehicle projects. This project included testing and documentation needed for installation, operation, enhancement, and maintenance of the units. These retrofit kits were built so they could be installed in existing class 6, 7, or 8 trucks. The RSD kits achieved a V2V and V2I functionality similar to that of the Connected Commercial Vehicles—Integrated Truck vehicles, where onboard equipment was integrated with newly manufactured truck tractors.

This document describes application requirements for CCV-RSD safety applications, including Forward Collision Warning (FCW), Intersection Movement Assist (IMA), Blind Spot Warning (BSW), Emergency Electronic Brake Lights (EEBL), and Curve Speed Warning (CSW). Safety applications based on these requirements were subsequently implemented in the CCV-RSD program as an adaptation of a preexisting system developed for Light Vehicles and the CCV-Integrated Truck (CCV-IT) program.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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LIST OF ABBREVIATIONS

BSW/LCW	Blind Spot Warning / Lane Change Warning
CAMP	Crash Avoidance Metrics Partnership
CCV	Connected Commercial Vehicle
CICAS-V	Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations
CSW	Curve Speed Warning
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EEBL	Emergency Electronic Brake Lights
EEBL-HV	EEBL Warning
EEBL-RV	EEBL Remote Vehicle Self-Identification
FCW	Forward Collision Warning
HV	Host Vehicle
IMA	Intersection Movement Assist
IT	Integrated Truck
ITIS	International Traveler Information Systems
LV	Light Vehicles
RSD	Retrofit Safety Device
RV	Remote Vehicle

SDH	Sensor Data Handler
TA	Threat Arbitration
TC	Target Classification
TIM	Traveler Information Message
USDOT	United States Department of Transportation
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
V2V-SP	Vehicle-to-Vehicle – Safety Pilot
VSC2	Vehicle Safety Consortium 2
VSC-A	Vehicle Safety Communications – Applications
WMH	Wireless Message Handler

EXECUTIVE SUMMARY

This document describes the targeted list of safety applications and associated development plan for the Connected Commercial Vehicles—Retrofit Safety Device (CCV-RSD) Kit Project, and is deliverable under task 4.

This document describes application requirements for CCV-RSD safety applications, key software modules, application scenarios, and basic assumptions. The safety applications being delivered for the CCV-RSD program include Forward Collision Warning (FCW), Intersection Movement Assist (IMA), Blind Spot Warning / Lane Change Warning (BSW/LCW), Emergency Electronic Brake Lights (EEBL), and Curve Speed Warning (CSW). These safety applications will be implemented in the CCV-RSD program as an adaptation of a preexisting system developed for Light Vehicles and the CCV-Integrated Truck (CCV-IT) program.

The software architecture includes the ability to add applications at a future date — including applications that use information from the vehicle's data-bus, exchange information with infrastructure applications and/or other connected vehicles via the 5.9 GHz Dedicated Short Range Communications (DSRC) radio, and interface with the Driver-Vehicle Interface (DVI) platform.

CHAPTER 1. INTRODUCTION

The safety application development portion of the CCV-RSD project is structured largely as an adaptation of a preexisting system developed over multiple LV projects and the CCV-IT program. LV system development was initiated in 2006 by the Crash Avoidance Metrics Partnership (CAMP) Vehicle Safety Communications 2 (VSC2) Consortium (Ford Motor Company, General Motors Corporation, Honda R&D Americas, Inc., Mercedes-Benz Research and Development North America, Inc., and Toyota Motor Engineering & Manufacturing North America, Inc.) for the U.S. Department of Transportation (USDOT) Cooperative Intersection Collision Avoidance System Limited to Stop Sign and Traffic Signal Violations (CICAS-V) project. Development continued in the Vehicle Safety Communications – Applications (VSC-A) project based on the platform used for the CICAS-V project. The platform is again being used and modified for vehicle safety communications research in the Vehicle-to-Vehicle – Safety Pilot (V2V-SP) project.

Due to the nature of this project and its foundation in technology from earlier projects, this document focuses on the new or modified areas of the platform developed expressly for the CCV-RSD project. Detailed information on the baseline platform and safety applications specifications and designs can be found in USDOT documentation from the above referenced projects, especially those from the VSC-A and CCV-IT projects. CSW is a new safety application, adapted from the CCV-IT project, not previously developed by CAMP, but still based on the same software architecture and core modules originating in the above projects. Also, since CSW application development requires a stable definition of the Traveler Information Message (TIM) structure and content supplied by the Roadside Equipment, firm requirements as well as design will depend, in part, on the availability of stable message content and structure. In the absence of a stable TIM, the CCV-RSD applications team may opt to develop and implement its own TIM functionality in order to prove the CSW application and potentially provide guidance to the TIM standardization process.

This document is largely adapted from the CCV-IT Application Requirement draft document submitted by Mercedes Benz Research & Development North America, Inc., for the CCV-IT project.[(1)]

CHAPTER 2. SAFETY APPLICATIONS

2.1 APPLICATIONS

Five safety applications were implemented. Four communicate with other vehicles (V2V) for avoiding multiple-vehicle crashes, and one communicates with the infrastructure (V2I) for avoiding single-vehicle crashes.

2.1.1 Forward Collision Warning (FCW)

Forward Collision Warning is a vehicle-to-vehicle (V2V) communications based safety feature that issues a warning to the driver of a vehicle in case of an impending rear-end collision with a vehicle ahead in the same lane and direction of travel. The vehicle can be moving or stopped. FCW will help drivers in avoiding or mitigating rear-end vehicle collisions in the forward path of travel.

2.1.2 Intersection Movement Assist (IMA)

Intersection Movement Assist is a V2V communications based safety feature that warns the vehicle driver when it is not safe to enter an intersection due to high probability of collision with other vehicles approaching the intersection from crossing paths. IMA is primarily intended to help drivers avoid or mitigate vehicle collisions at stop sign controlled and uncontrolled intersections.

2.1.3 Blind Spot Warning and Lane Change Warning (BSW/LCW)

Blind Spot Warning / Lane Change Warning is a V2V communications based safety feature that warns the vehicle driver if the blind spot zone into which the driver intends to move is, or will soon be occupied by another vehicle traveling in the same direction during a lane change attempt. Moreover, the application provides advisory information to the driver whenever a vehicle in an adjacent lane is positioned in their blind spot. A lane change attempt is recognized by the driver's use of the turn signal.

2.1.4 Emergency Electronic Brake Lights (EEBL)

Emergency Electronic Brake Lights is a V2V communications based safety feature that informs or warns a following vehicle's driver if a leading vehicle is engaging their brakes and decelerating above a predetermined threshold. Upon receiving braking information from the leading vehicle, the following vehicle determines the relevance and severity of the event and provides an advisory or warning to the driver, if appropriate. This application is particularly useful when the driver's line of sight is obstructed by other vehicles or in bad weather conditions (e.g. fog, heavy rain).

2.1.5 Curve Speed Warning (CSW)

Curve Speed Warning is a vehicle-to-infrastructure (V2I) communications based safety feature that informs or warns the driver if the vehicle is in danger of exceeding the recommended speed for an upcoming curve. The vehicle receives curve information from roadside equipment (e.g. recommended speed, curve start, end, and direction), determines if the curve is relevant, and provides an advisory or warning to the driver, if appropriate.

2.2 SOFTWARE ARCHITECTURE

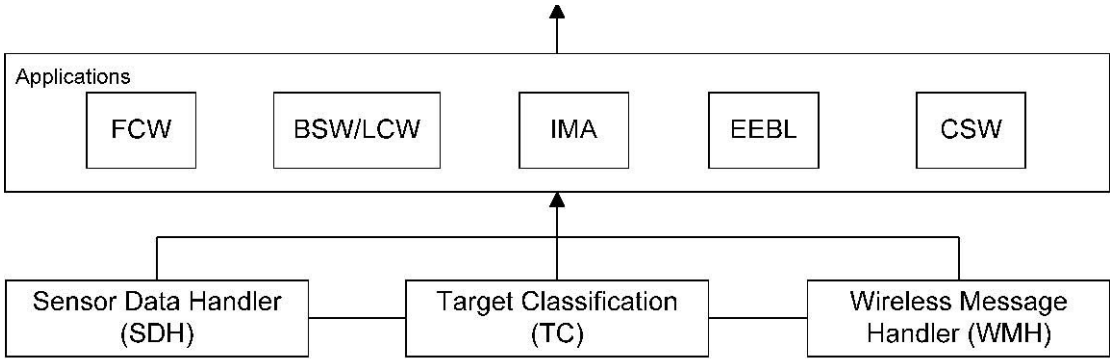

Figure 1. Chart. Software architecture.

2.2.1 Supporting Modules

2.2.1.1 Sensor Data Handler

Sensor Data Handler (SDH) is a module that monitors the status of the host vehicle (HV). It provides the following information:

- Host vehicle speed.
- Host vehicle current gear (if available).
- Timestamp of the current GPS reading.
- Host vehicle brake status.
- Host vehicle length.
- Longitudinal acceleration.

2.2.1.2 Wireless Message Handler

Wireless Message Handler (WMH) is a module that communicates with remote (neighboring) vehicles (RV) and infrastructure. From over the air messages, WMH can provide the following information about each remote vehicle to the host vehicle:

- Remote vehicle ID.
- Remote vehicle speed.
- Remote vehicle position.

- Remote vehicle longitudinal acceleration.
- Remote vehicle brake status.

2.2.1.3 Target Classification

Target Classification (TC) is a module that classifies the locations of remote vehicles relative to the host vehicle. For each of the remote communicating vehicles, TC would provide the following information relative to the local host vehicle:

- Relative location of a remote vehicle, classified into zones shown in figure 2.
- Range and heading of a remote vehicle.
- Relative speed of a remote vehicle.
- Relative longitudinal and lateral distance, as illustrated by figure 3.
- Confidence level of target tracking.

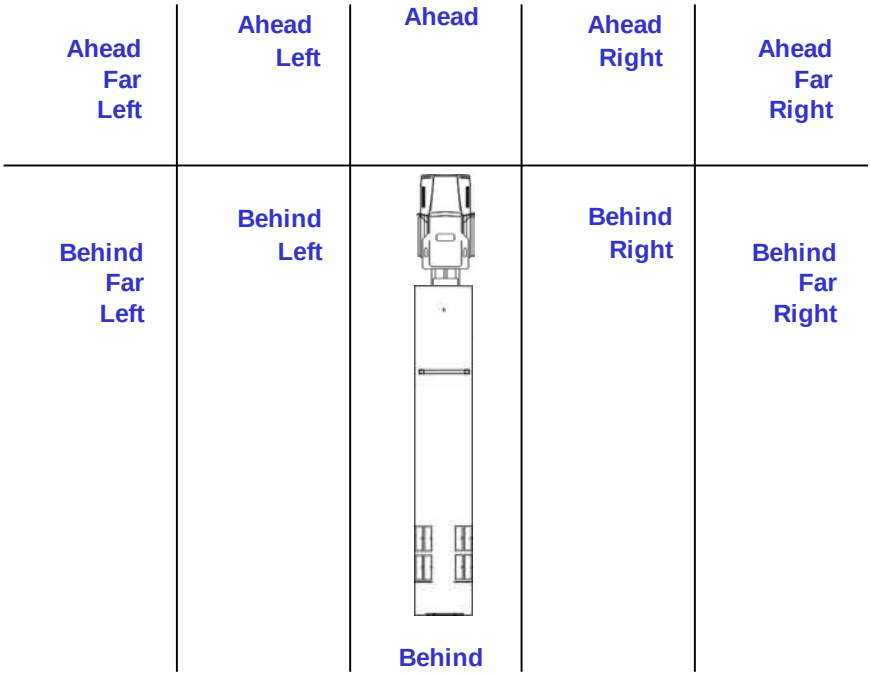

Figure 2. Sketch. TC location zones.

2.2.1.4 Threat Arbitration

The Threat Arbitration (TA) module arbitrates between all safety applications warning requests to resolve driver notification conflicts should they occur. In order to ensure the most important warning request is sent to the driver, this module uses threat level, relative speed, location of threat, and other information from each safety module to assess relative severity. It then determines the highest priority warning request and triggers notification of this warning to the driver.

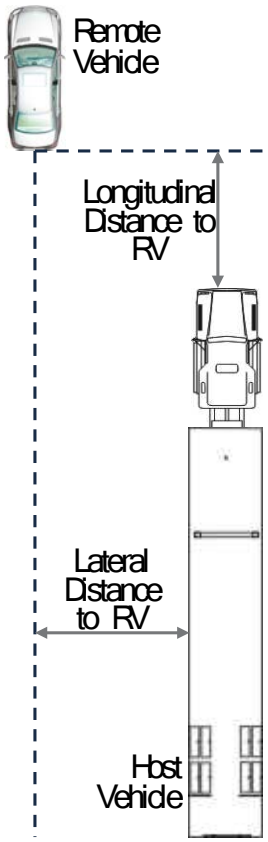

Figure 3. Sketch.
TC relative distances.

CHAPTER 3. APPLICATION REQUIREMENTS

This chapter presents in detail the requirements for the RSD to provide each of the safety applications.

3.1 FCW

3.1.1 Scenario

FCW shall inform or warn the HV driver if an ahead (same lane, same direction) RV is moving slower than the HV or is stopped.

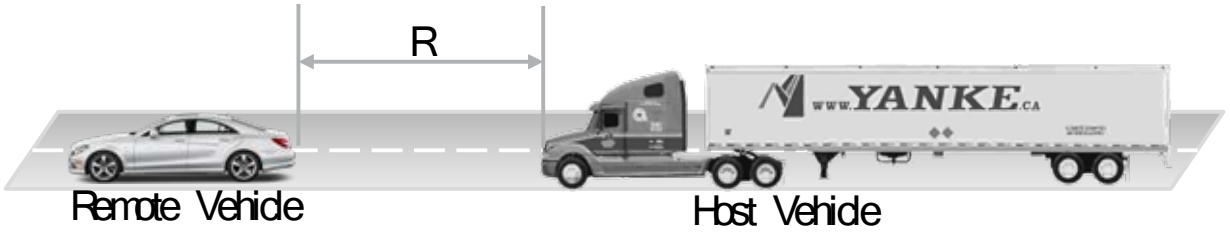

Figure 4. Sketch. FCW scenario.

3.1.2 Design Assumptions

- FCW logic flow will be executed either periodically or when a new vehicle is detected by the TC module.
- Only remote vehicles identified as AHEAD by the TC module will be processed by the FCW application.

3.1.3 Application Requirements

3.1.3.1 User Requirements

- FCW shall be capable of being turned ON or OFF.
- FCW shall provide warning information to the driver only when the speed of the host vehicle is at least above a configurable threshold.
- FCW shall warn the driver of the host vehicle when there is imminent danger of a rear-end collision with a remote lead vehicle in its lane of travel.
- When the FCW warning is determined, it shall persist for a configurable duration.
- FCW shall suppress a warning if the host vehicle is applying sufficient brake at the time the warning would normally be issued.
- FCW shall be capable of providing multi-stage warnings to indicate cautionary and imminent threat levels.

3.1.3.2 Functional Requirements

1. FCW shall transition between one of the following FCW states:

   - DISABLED: The FCW feature is disabled.
   - ENABLED: The FCW feature is enabled.
   - ENGAGED: The FCW feature is engaged.
   - FAILED: The FCW feature is unavailable because of one or more failures/faults in the system.

2. FCW shall enter the ENABLED state by default when the System Power is switched ON. FCW shall reset to the ENABLED state following all power cycles.

3. FCW shall transition from ENABLED to ENGAGED if the following conditions are valid:

   - Host vehicle speed is above the configured threshold speed.
   - Host vehicle is moving in the forward direction.

4. When FCW is ENGAGED, FCW shall periodically process inputs from the following subsystems: TC, SDH, and WMH.

   - FCW shall select all remote target vehicles classified as AHEAD in lane by the TC module with longitudinal range less than a configurable threshold.
   - FCW shall process all selected remote target vehicles and evaluate the threat level for each one.

5. Threat level shall be assigned an integer value between 0 and 100.

6. FCW shall select the remote target vehicle with the highest threat level and output the information to the TA module.

7. FCW warning state should be assigned as one of the following:

   - NONE.
   - DETECTED.
   - INFORM.
   - WARN.

8. When the FCW warning state is INFORM or WARN, it shall remain in that state for a defined minimum duration.

9. The FCW warning state shall be reset to NONE following detection that the host vehicle has brakes active. The driver is assumed to be aware of the situation and is preparing to take action.

10. FCW shall completely process the assessment within a defined latency from the reception of incoming messages in the WMH.

3.1.4 Inputs

FCW receives updates from the TC, SDH, and WMH modules every 100 ms.

3.1.5 Outputs

FCW shall send at least the following information to the TA module:

- FCW application state.
- Current FCW warning state.
- In case a threat from a remote vehicle is detected, the following remote vehicle information shall be included:
  - Vehicle Identifier.
  - Relative location of the remote vehicle.
  - Longitudinal Offset.
  - Relative Speed.
  - Associated FCW threat level.

3.2 IMA

3.2.1 Scenario

IMA's scope shall be limited to the following scenarios and phases.

3.2.1.1 Scenario 1: Two Vehicles Approaching an Intersection

In this scenario two vehicles whose paths are roughly perpendicular are approaching the intersection point. This is commonly seen at uncontrolled intersections. This scenario is distinguished from Scenario 2 in that both vehicles are traveling above a configurable threshold speed and neither vehicle has their brake applied.

In this scenario the driver is informed if the Host Vehicle is a predetermined, configurable distance away from the intersection point.

A warning is issued if the Host Vehicle is within the critical stopping distance from the intersection point.

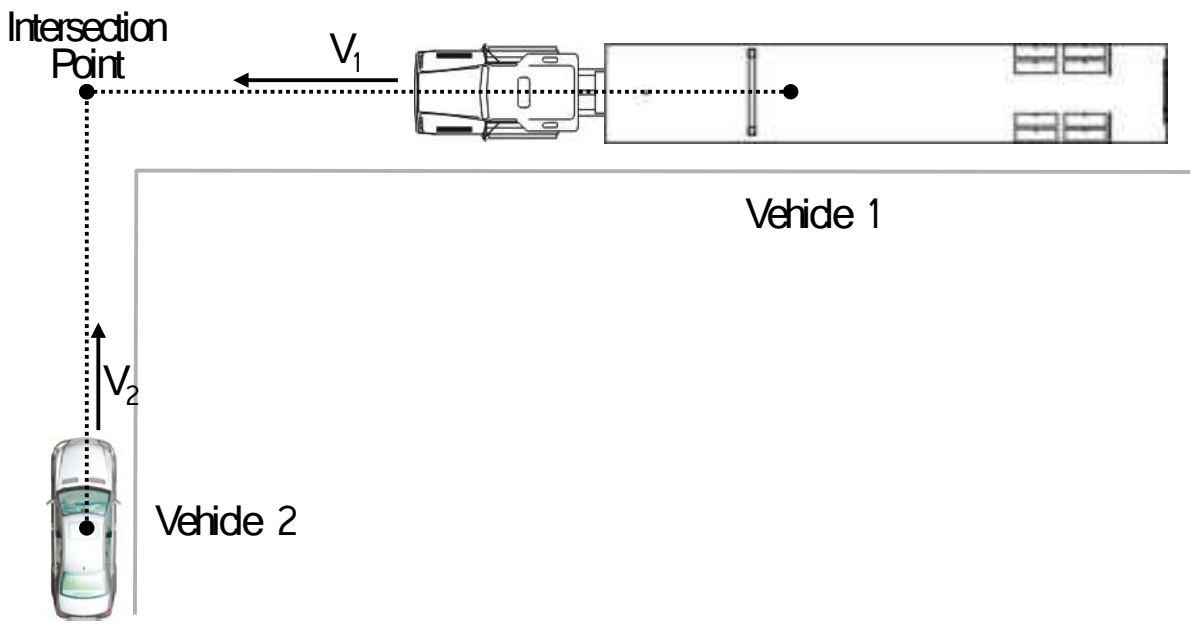

Figure 5. Sketch. IMA scenario 1.

3.2.1.2 Scenario 2: Two-Way Stop

In this scenario one vehicle is attempting to cross or merge into a perpendicular route of travel. This may be seen at any road-intersection containing only two stop signs, where parking lots spill out onto regular roads, and where rural highways intersect with other roads.

At the beginning (in time) of this scenario one vehicle will be stopped with its brake applied. A second vehicle is traveling on a route (roughly) perpendicular to the first vehicle's heading, possibly posing a collision threat should the first vehicle creep forward.

In this scenario the warnings and informs issued to the drivers of each vehicle will be asymmetric. This Scenario is broken down into two phases: Vehicle 1 with its brake applied and Vehicle 1 with its brake not applied with very minimal speed (creeping forward).

3.2.1.3 Phase 1: Vehicle 1 Braking

In this phase vehicle 1 has its brake applied. This is the distinguishing characteristic between phase 1 and phase 2 for scenario 2.

Vehicle 1 shall receive an Inform if vehicle 2 is within range of posing a collision threat. Vehicle 2 shall not receive either a warning or an Inform from IMA at any time during this phase.

3.2.1.4 Phase 2: Vehicle 1 Creeping Forward

In this phase vehicle 1 is no longer applying its brake and begins creeping forward. Vehicle 1 remains at very low speed. At this time it is impossible to determine if the driver of vehicle 1 is

attempting to creep forward to see around sight-blocking vehicles, or if the driver is preparing to apply the gas to progress forward either across the intersection or to turn and merge into traffic on the intersecting road.

Vehicle 1 shall receive a warning (and only a warning) during this phase if vehicle 2 is within range of posing a collision threat (within the critical stopping distance). No inform will be issued during this phase to vehicle 1 by IMA.

Vehicle 2 shall now receive an Inform if it is within a preset multiplier of the critical stopping distance. No warning is issued in this phase to vehicle 2 by IMA.

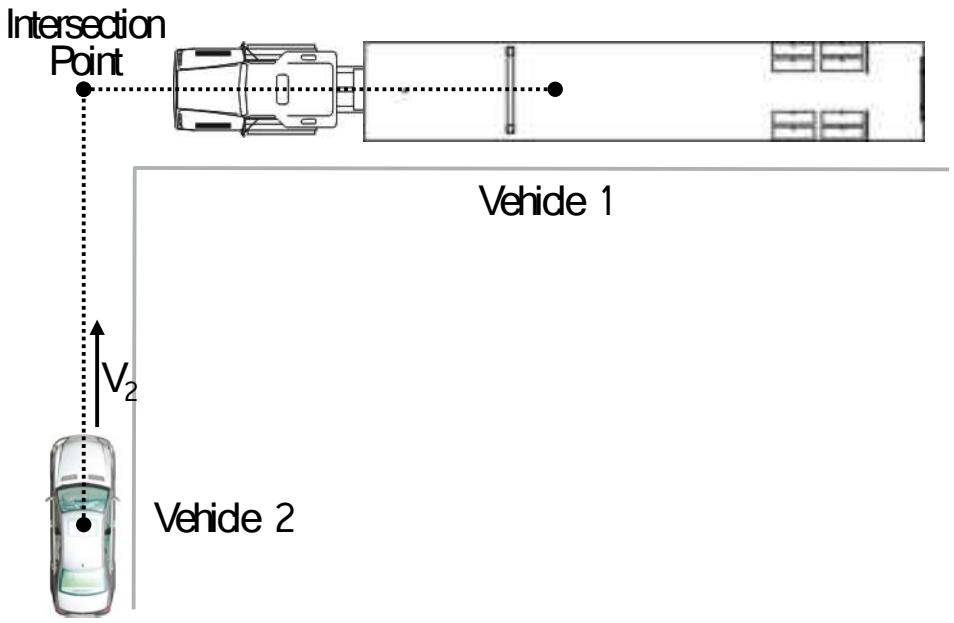

Figure 6. Sketch. IMA scenario 2.

3.2.2 Design Assumptions

- IMA logic flow will be executed when a new object is detected by the TC module.
- Only remote vehicles identified as LEFT or RIGHT by the TC module will be processed.

3.2.3 Application Requirements

3.2.3.1 User Requirements

- IMA shall be capable of being turned ON or OFF.
- IMA shall be capable of computing threat level for all RVs classified as either intersecting from left or right if they are within a defined range.
- IMA shall assign multi-stage warning levels to each RV commensurate with their threat level.

- IMA shall provide warning information to TA about the highest threat RV intersecting from left (if any) and the highest threat RV intersecting from right (if any).
- When the IMA warning is determined, it shall persist for a configurable duration and continue as long as no corrective action is taken that sufficiently avoids the collision danger.
- IMA shall suppress a warning if the HV and/or RV driver is reducing speed or changing path to avoid collision.

3.2.3.2 Functional Requirements

1. IMA shall transition between one of the following IMA states:

   - DISABLED: The IMA feature is disabled.
   - ENABLED: The IMA feature is enabled.
   - ENGAGED: The IMA feature is engaged.
   - FAILED: The IMA feature is unavailable because of one or more failures/faults in the system.

2. IMA shall enter the ENABLED state by default when the System Power is switched ON.

3. IMA shall transition from ENABLED to ENGAGED if there are any RVs reported by TC as either intersecting left or right within a defined range.

4. When IMA is ENABLED, IMA shall periodically process inputs from the TC, SDH, and WMH modules every 100 ms. IMA shall determine if a collision is imminent based on the remote vehicles detected by TC and by monitoring its own brake status, longitudinal acceleration, speed, and heading.

5. IMA shall have four stages of warning: NONE, DETECTED, INFORM, and WARN.

6. IMA shall ignore all RVs when both RV and HV are traveling at a speed below a minimal speed threshold.

7. IMA shall report a DETECTED status for each TC target location (intersecting right and intersecting left) for which TC reports active RVs within a preset maximum range. Any reporting of an INFORM or WARN threat level for either location shall supersede the DETECTED status.

8. (WARN Conditions) While IMA is in the ENGAGED state, IMA shall set a WARN threat level for all RVs classified as intersecting left or intersecting right if any of the following are true:

   - (Scenario 1 (Symmetric)) If both the HV and RV are traveling at a speed at or above a minimal speed threshold and will be arriving at the intersection point at roughly the same time and also the HV is within critical stopping distance.

- (Scenario 2 Phase 2 Vehicle 1) If the HV is traveling below a minimal speed threshold but the RV is traveling at a speed above the minimal speed threshold and the HV does not have its brakes applied and the HV is within critical stopping distance.

9. A WARN report to TA shall be suppressed if the HV changes course to avoid a collision (difference between HV time to intersection and RV time to intersection exceeds the time a vehicle need to cross the intersection) at the time the warning would normally be issued.

10. (INFORM Conditions) While IMA is in the ENGAGED state, IMA shall set an INFORM threat level for all RVs classified as intersecting left or intersecting right if any of the following are true:

    - (Scenario 1 (Symmetric)) If both the HV and RV are traveling at a speed at or above a minimal speed threshold and will be arriving at the intersection point at roughly the same time and the HV is not yet at the critical stopping distance.

    - (Scenario 2 Phase 1 Vehicle 1) The HV is traveling at a speed below a minimal speed threshold together with its brake applied, the HV is within a preset distance to intersection, the RV is traveling above a minimum speed threshold, and the RV is within a preset multiplier of the critical stopping distance for the RV's current speed.

    - (Scenario 2 Phase 2 Vehicle 2) The HV is traveling at or above a minimum speed threshold, the RV is traveling below a minimum speed threshold, the RV does not have its brake applied, the RV is within a preset distance to the intersection, and the HV is within a preset multiplier of its critical stopping distance.

11. IMA shall indicate from which direction an RV is predicted to impact the HV by setting the threat location appropriately to LEFT or RIGHT.

12. IMA threat level shall be assigned an integer value between 0 and 100.

13. IMA will assign a threat level for each processed RV. The RV with the highest threat level will be passed to the Threat Arbitration module.

Special Terms

- "Critical Stopping Distance" is the distance to stop for the vehicle under consideration.
- "Distance To Intersection" is the distance between the vehicle's front bumper and the intersection boundary.

3.2.4 Inputs

IMA receives updates from the TC, SDH, and WMH modules every 100 ms.

3.2.5 Outputs

IMA shall output at least the following information to the TA module:

- IMA application state.
- Current IMA warning state: NONE, DETECTED, INFORM, or WARN.
- Location of a detected IMA threat (LEFT, RIGHT), if any.
- Threat level of the detected IMA threat.

3.3 BSW/LCW

3.3.1 Scenario

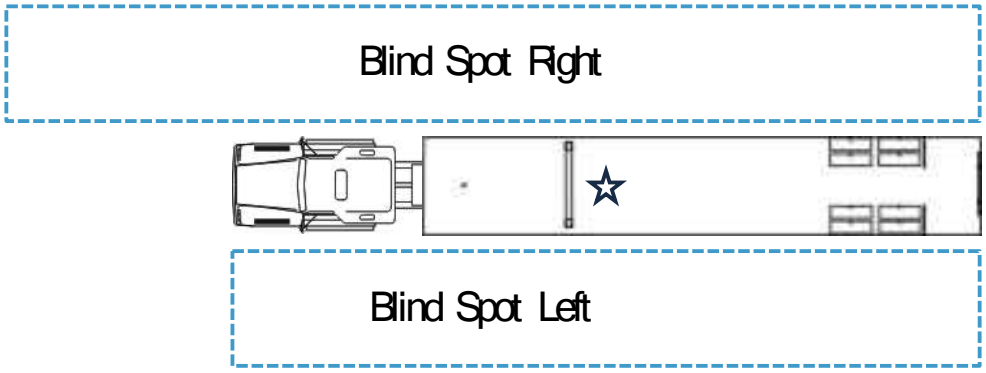

Figure 7. Sketch. BSW/LCW scenario.

Note: In figure 7, lateral and longitudinal distance offsets are relative to host vehicle geometric center (star).

Note: A remote vehicle position for BSW/LCW is referred to by the center of the remote vehicle's bumper (not the remote vehicle geometric center).

3.3.2 Design Assumptions

- BSW/LCW logic flow will be executed either periodically or when a new object is detected by the TC module.
- A lane change warning will only be given if the turn indicator status is available and the turn indicator is ON.
- Blind spot zone may differ between driver-side and passenger-side blind spots.
- Only remote vehicles identified as behind left or behind right by the TC module will be processed.
- Remote vehicles that are currently ahead of the host vehicle but could possibly fall back into the blind spot zone are not considered threats.

3.3.3 Application Requirements

3.3.3.1 User Requirements

- BSW/LCW shall be capable of being turned ON or OFF.
- BSW/LCW shall inform the HV driver whenever a remote vehicle is located within a blind spot zone of the HV.
- BSW/LCW shall provide information and warnings to the HV driver only when the HV is traveling above a defined minimal speed threshold.
- BSW/LCW shall warn the HV driver only when:
  - The left turn indicator status is available and is on and at least one RV is in or will be in the left blindspot.
  - The right turn indicator status is available and is on and at least one RV is in or will be in the right blindspot.
- When a BSW/LCW warning is determined, it shall persist at least for a defined duration of time.
- BSW/LCW shall provide informs and warnings to the HV driver regarding a particular RV only when that RV is traveling at a speed above a defined threshold.

3.3.3.2 Functional Requirements

1. BSW/LCW shall transition between one of the following states:

   - DISABLED: The BSW/LCW functionality is disabled.
   - ENABLED: The BSW/LCW functionality is enabled.
   - INFORM: The BSW/LCW functionality informs the HV driver of a vehicle(s) currently in a blind spot zone.
   - WARN: The BSW/LCW functionality warns the HV driver who is intending to change lanes that a vehicle(s) is currently or soon will be, in a blind spot zone.
   - FAILED: The BSW/LCW functionality determines that insufficient information from other modules is available for the BSW/LCW feature logic to function properly.

2. BSW/LCW shall enter the ENABLED state by default when the System Power is switched ON.

3. BSW/LCW shall transition from ENABLED to DISABLED state when the enable state is set to FALSE.

4. BSW/LCW shall transition from DISABLED to ENABLED state when the following conditions are satisfied:

   - The System Power is ON.
   - The enable state is set to TRUE.

5. BSW/LCW will use TC output to further classify RVs in behind-left and behind-right locations as possible threat vehicles in or will be in left or right blindspots.

6. BSW/LCW shall use these classifications for the RVs to inform the HV driver of any threat vehicles that are currently occupying the blind spot zones of the HV.

7. BSW/LCW shall use the HV's turn signal status (when available) and classifications for RVs to warn the HV driver of any threat vehicles occupying the blind spot zone in the adjacent lanes into which the HV driver proposes to maneuver.

8. BSW/LCW shall transition from ENABLED to INFORM state if the following conditions are valid:

    - HV speed is above the defined speed threshold.
    - HV turn indicator status is OFF (or indicator status is unavailable).
    - At least one threat vehicle is positioned in a blindspot.
    - RV speed is above the defined speed threshold.

9. BSW/LCW shall transition from ENABLED to WARN state if the following conditions are valid:

    - HV speed is above the defined speed threshold.
    - HV left or right turn indicator status is on (and indicator status is available).
    - If left turn indicator of HV is on, and at least one RV is classified as in left blindspot or will be in left blindspot.
    - If right turn indicator of HV is on, and at least one RV is classified as in right blindspot or will be in right blindspot.
    - RV speed is above the defined speed threshold.

10. When BSW/LCW is in WARN state, BSW/LCW shall continue to provide advisory information to TA of any threat vehicles currently in the opposite blind spot zone.

11. BSW/LCW shall assign a threat level (between 0-100) to all RVs.

12. For each blind spot zone, the RV with the highest threat level will be passed by BSW/LCW to TA.

13. When BSW/LCW enters the WARN state, it shall remain in that state at least for a defined duration of time.

14. BSW/LCW shall transition from INFORM to WARN if the following conditions are valid:

    - HV speed is above the defined speed threshold.
    - HV left or right turn indicator status is on (and indicator status is available).
    - If left turn indicator of HV is on, and at least one RV is classified as in left blindspot.

- If right turn indicator of HV is on, and at least one RV is classified as in right blindspot.
- RV speed is above the defined speed threshold.

3.3.4 Inputs

BSW/LCW receives updates from the TC, SDH, and WMH modules every 100 ms.

3.3.5 Outputs

BSW/LCW shall send at least the following information to the TA module:

- BSW/LCW state: DISABLED, ENABLED, INFORM, WARN, or FAILED.
- BSW/LCW threat location: in left, right, or both blindspots.
- BSW/LCW threat ID left and/or right.
- BSW/LCW threat level left and/or right.
- BSW/LCW threat longitudinal offset left and/or right.
- BSW/LCW threat relative velocity left and/or right.
- BSW/LCW warn state: NONE, DETECTED, INFORM, or WARN.

3.4 EEBL

3.4.1 Scenario

The application is divided into two sub-applications:

- EEBL Remote Vehicle Self-Identification: EEBL-RV.
- This sub-application monitors the vehicle brake and deceleration status, and updates the event status accordingly.
- EEBL Warning: EEBL-HV.
- This sub-application identifies EEBL threat vehicles, assesses the threat and warning levels, and issues warnings accordingly.

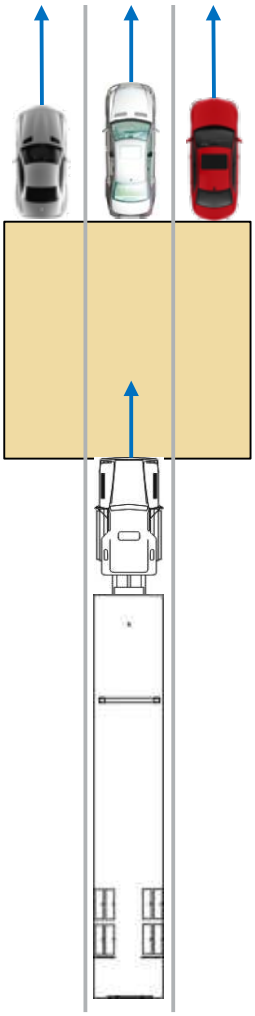

Figure 8. Sketch. EEBL scenario.

3.4.2 Design Assumptions

- EEBL-RV logic flow can be executed periodically or event driven to detect the EEBL event generated by the vehicle. It will alert the WMH as a trigger for an immediate outgoing message.
- EEBL-HV shall be event driven, triggered by the EEBL event flag, set by WMH.
- Only vehicles ahead, ahead left, or ahead right will be considered for EEBL-HV processing.

3.4.3 Application Requirements

3.4.3.1 User Requirements for EEBL-RV

- EEBL-RV shall be capable of being turned ON or OFF.
- EEBL-RV shall be capable of setting the EEBL-RV event flag when it detects RV hard braking.

3.4.3.2 Functional Requirements for EEBL-RV

1. EEBL-RV shall transition between one of the following states:

    - DISABLED: EEBL-RV feature is disabled.
    - ENABLED: EEBL-RV feature is enabled.
    - ENGAGED: EEBL-RV is monitoring the relevant data inputs and updating the EEBL-RV status.
    - FAILED: EEBL-RV is unavailable because of one or more failures/faults in the system.

2. EEBL-RV shall be in the ENABLED state when System Power is switched to ON.

3. EEBL-RV state shall transition from ENABLED to DISABLED state when the EEBL-RV enabled is FALSE.

4. EEBL-RV shall transition from DISABLED to ENABLED state when the following conditions are satisfied:

    - The system power is ON.
    - EEBL-RV enable is TRUE.
    - EEBL-RV failure is FALSE.

5. EEBL-RV enable state shall be TRUE by default.

6. EEBL-RV state shall transition from ENABLED to ENGAGED if the following conditions are satisfied:

    - EEBL-RV state is ENABLED.
    - RV speed is above a predefined threshold.

7. When EEBL-RV state is ENGAGED, EEBL-RV shall process inputs from the Sensor Data Handler at least every 100 ms.

8. EEBL-RV Status shall be set to FALSE by default.

9. EEBL-RV shall set its Status to TRUE if the vehicle brakes above a preset threshold.

3.4.3.3 User Requirements for EEBL-HV

- EEBL-HV shall be capable of being turned ON or OFF.
- EEBL-HV shall be capable of warning the driver only when the host vehicle speed is above a specified threshold.
- EEBL-HV shall warn the driver when the host vehicle determines that there is a threat.
- When EEBL-HV issues a warning, it shall persist for at least a predetermined duration.

- EEBL-HV shall suppress the warning if the host vehicle applies sufficient brake.
- EEBL-HV shall be capable of providing multi-stage warnings to indicate level of urgency.

3.4.3.4 Functional Requirements for EEBL-HV

1. EEBL-HV shall transition between one of the following states:

    - DISABLED: EEBL-HV feature is disabled.
    - ENABLED: EEBL-HV feature is enabled.
    - ENGAGED: EEBL-HV is monitoring the target vehicle(s) data inputs and updating the EEBL threat level(s).
    - FAILED: EEBL-HV is unavailable because of one or more failures/faults in the system.

2. EEBL-HV state shall be set to ENABLED when System Power is ON.

3. EEBL-HV shall transition from ENABLED to DISABLED state when EEBL-HV enabled is FALSE.

4. EEBL-HV shall transition from DISABLED to ENABLED state when the following conditions are satisfied:

    - The system power is ON.
    - EEBL-HV enable is TRUE.
    - EEBL-HV failure is FALSE.

5. EEBL-HV enable shall be TRUE by default.

6. EEBL-HV shall transition from ENABLED to ENGAGED state if the following conditions are valid:

    - EEBL-HV state is ENABLED.
    - HV speed is above a preset threshold.

7. When EEBL-HV is ENGAGED, EEBL-HV shall continuously process inputs from the following subsystems: Target Classification, Sensor Data Handler, and Wireless Data Handler every 100 ms.

    - EEBL-HV shall select the threat vehicle(s) that satisfy the following conditions:
        - Classified as one of the followings: Ahead, Ahead Left, or Ahead Right.
        - Longitudinal offset from RV's rear bumper to the host vehicle's front bumper is less than the preset maximum range.
        - EEBL-RV Status is TRUE (identified by the event flag in the incoming messages).
        - During the EEBL event, HV detects that RV's braking exceeds a pre-defined deceleration value from the time HV first receives the EEBL-RV status as True.

- EEBL-HV shall process all threat vehicles to set the warning state(s) and to calculate threat levels for each remote (threat) vehicle.
  - EEBL WARN shall be NONE by default.
  - EEBL WARN shall be set according to the threat level.
  - When EEBL WARN is WARN, it shall remain in that level for at least a specified minimum amount of time.
  - EEBL threat level shall be NONE if the host vehicle applies or has already applied sufficient brakes to avoid a collision with the RV.

- EEBL-HV shall select the RV with the highest EEBL threat level and output this data and other threat related data to the Threat Arbitration module.

3.4.4 Inputs

EEBL receives updates from the Target Classification, Sensor Data Handler, and Wireless Data Handler modules every 100 ms.

3.4.5 Outputs

EEBL shall send at least the following information to the Threat Arbitration module:

- EEBL-RV state: DISABLED, ENABLED, ENGAGED, or FAILED.
- EEBL-RV Status: TRUE, FALSE.
- EEBL-HV state: DISABLED, ENABLED, ENGAGED, or FAILED.
- EEBL-HV threat location: AHEAD, AHEAD LEFT, or AHEAD RIGHT).
- EEBL-HV threat ID.
- EEBL-HV threat level (per threat ID).
- EEBL-HV threat longitudinal offset (per threat ID).
- EEBL-HV threat Relative Velocity (per threat ID).
- EEBL-HV WARN state: NONE, DETECTED, INFORM, or WARN.

3.5 CSW

3.5.1 Scenario

CSW shall inform or warn the HV driver if the HV speed is faster than the advised speed when it is approaching a curve.

3.5.2 Design Assumptions

- RSE shall broadcast a Traveler Information Message (TIM) periodically.
- WMH shall extract all available Curve Sign data (corresponding to ITIS codes 13609 and 13610) from TIM messages received by the HV.

- Curve Sign data included in a TIM shall include:
  - The curve's advisory speed.
  - Position and directionality information describing the "start" of the curve.
  - Position and directionality information describing each "region" of the curve.

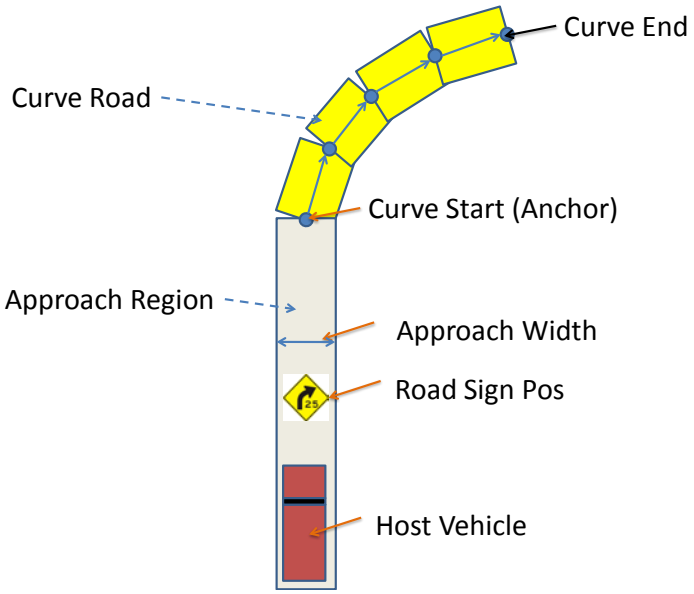

Figure 9. Sketch. CSW scenario.

3.5.3 Application Requirements

3.5.3.1 User Requirements

- CSW shall be capable of being turned ON or OFF.
- CSW shall provide a warning or cautionary inform to the driver only when the speed of the host vehicle exceeds a configurable threshold.
- CSW shall allow adjustment to the target curve speed, depending on the type of host vehicles or host vehicle configurations.
- CSW shall be capable of providing warning or cautionary inform depending on the imminent threat levels.
- CSW will provide cautionary inform when a relevant curve is ahead and the distance to the curve start is less than the comfortable braking distance, which is calculated using the current vehicle speed and target curve speed ahead.
- CSW will provide warning when a relevant curve is ahead and the distance to the curve start is less than the emergency braking distance, which is calculated using the current vehicle speed and target curve speed ahead.
- CSW shall suppress advisory / warning if the HV is not located within any of the curve regions provided in the TIM Curve Speed Sign data.

3.5.3.2 Functional Requirements

1. CSW shall transit between one of the following CSW states:

   - DISABLED: The CSW feature is disabled.
   - ENABLED: The CSW feature is enabled.
   - ENGAGED: The CSW feature is engaged.
   - FAILED: The CSW feature is unavailable because of one or more failures/faults in the system.

2. CSW warning state shall be assigned as one of the following:

   - NONE.
   - DETECTED.
   - INFORM.
   - WARN.

3. CSW shall enter the ENABLED state by default when the System Power is switched on. CSW shall reset to the ENABLED state following all power cycles.

4. CSW shall transit from ENABLED to ENGAGED if the host vehicle speed is above the configured application threshold speed.

5. CSW shall transit from ENGAGED to ENABLED if the host vehicle speed is at or below the configured application threshold speed.

6. When CSW is ENGAGED, CSW shall perform the following periodically at a configurable interval:

   a. Compare the HV heading to TIM Curve Sign directionality information.
   b. If the heading matches the directionality for a particular curve, then calculate the HV distance to the start of that curve.
   c. If the distance to that Curve Sign is within a configurable range, then:
      - Calculate the target speed for the curve by combining the TIM Sign target speed with a configurable target speed adjustment (if available).
      - The CSW warning state shall transition to DETECTED if the HV speed is at or below the target speed for the curve.
      - If the HV position is before the start of the curve:
        - Calculate a comfortable braking distance to the start of the curve.
        - Calculate an emergency braking distance to the start of the curve.
        - The CSW warning state shall transition to INFORM if the HV speed is above the target speed for that curve, and the distance to the curve start is shorter than the comfortable braking distance, but longer than the emergency braking distance.

    - The CSW warning state shall transition to WARN if the HV speed is above the target speed for that curve, and the distance to the curve start is shorter than the emergency braking distance.
  - If the HV position is after the start of the curve but before the end of the curve:
    - The CSW warning state shall transition to WARN if the HV speed is above the target speed for that curve.

7. The CSW warning state shall be reset to NONE after the host vehicle has passed the end of the curve.

3.5.4 Inputs

The user shall enable CSW through the CSW_ENABLE switch.

The Sensor Data Handler module will provide vehicle:

- Position.
- Speed.
- Heading.
- Brake Status.
- PRNDL.
- Turn signal indicator Status.
- Longitudinal acceleration.
- SDH_SEQ_NUM (for relaying to Threat Arbitration block).
- SDH_STATE (for setting CSW_FAILURE).

The Wireless Message Handler module will provide:

- TIM data.
- WMH_SEQ_NUM (for relaying to Threat Arbitration block).
- WMH_STATE (for setting CSW_FAILURE).

Calibration parameters from Application Parameters file:

- CSW Minimum Speed Threshold.
- CSW maximum assumed braking factor.
- CSW advisory speed adjustment.

3.5.5 Outputs

CSW shall send at least the following information to the Threat Arbitration module:

- CSW state: DISABLED, ENABLED, ENGAGED, or FAILED.
- CSW most relevant curve speed sign ID.
- CSW distance to the most relevant curve start along the direction of travel.

- Target speed of the most relevant curve.
- Direction of the most relevant curve: left, right, ahead.
- Flag if the HV is located on a curve, between the start and end points of the curve: true or false.
- CSW threat level.
- Current speed of the host vehicle.
- CSW WARN state: NONE, DETECTED, INFORM, or WARN.
- CSW emergency braking distance.
- CSW comfortable braking distance.

APPENDIX A. WSU CONFIGURATION PARAMETERS FOR CONNECTED COMMERCIAL VEHICLES

The following table lists WSU configuration parameters that may need to be modified to account for differences between LVs and CCVs. These parameters are used in various WSU software modules and applications and make it possible to easily customize performance characteristics of these modules and applications to the vehicle hosting the OBE.

Parameter Name	Parameter Description	Implications
BSWLCWHorizonTimeS	A time horizon in which a closing vehicle must enter the blind spot zone to be considered "Will be in Blind Spot"	Increase default value to account for CCV longer lane change time
BSWLCWBsLengthLeftM	Length of the left blind spot zone	A CCV has a longer blind spot zone than LVs
BSWLCWBsLengthRightM	Length of the right blind spot zone	A CCV has a much longer blind spot zone on the right
EEBLMaxLongOffsetDistM	Longitudinal length of the EEBL zone	A longer EEBL zone is needed when CCV is the host vehicle
FCWMaxRangeM	Maximum longitudinal range for FCW application	Increase default value to account for longer CCV stopping distance
FCWDriverReactionTimeS	Assumed driver reaction time in s	May need longer reaction time for CCV drivers
FCWCaFollowCeilingFactor	Maximum host vehicle deceleration	Need to adapt to CCV braking
FCWCaFollowFloorFactor	Minimum host vehicle deceleration	Need to adapt to CCV braking
IMAMinCrossPathS	Minimum acceptable separation time (in seconds) between an HV and RV below whose absolute value a collision is possible	May need more time buffer for CCV in crossing paths

Parameter Name	Parameter Description	Implications
IMAMaxRvRangeM	Maximum range to intersection point that IMA considers RVs for warning or informing	May need longer default range to account for longer CCV stopping distance
IMABrakingSystemDelayS	Estimated response time for a braking system from brake pedal press to brake application	Adapt to CCV braking profile
IMABrakingConstant	A unitless braking parameter representing a fraction of gravitational acceleration	Need to adapt to CCV braking system
IMAInformMultiplier	A unitless multiplier used to determine the size of the inform zone based on the size of the warn zone	May need to adjust default value
COMMONAntAdjXm	Longitudinal offset adjustment if GPS antenna is not installed at the center of the vehicle	Need to allow for CCV size and changes in configuration
COMMONAntAdjYm	Lateral offset adjustment if GPS antenna is not installed at the center of the vehicle	Need to allow for CCV size and changes in configuration
COMMONMultiRadioEnable	Enable/Disable simultaneous dual radio use for WMH/VSC-A	May adjust for dual WSUs

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