# Cooperative Automated Driving Systems to Improve Freeway Mobility (CADS-IFM)

Concept of Operations

Draft Version 1.6

# 1. Introduction

## 1.1 Background

This document describes a concept for Cooperative Automated Driving Systems for Improved Freeway Mobility (CADS-IFM), a joint effort between the Crash Avoidance Metrics Partners (CAMP) LLC and the United States Department of Transportation (USDOT), to explore how connected vehicle (CV) systems can improve automated vehicle (AV) operations and freeway mobility.

CAMP and USDOT have already collaboratively developed and demonstrated Cooperative Adaptive Cruise Control (CACC) under controlled settings. The fundamental CACC concept involves merging Adaptive Cruise Control (ACC), a subset of the broader class of automated speed control systems, with cooperative Vehicle-to-Vehicle (V2V) communications. V2V communications could provide information about the vehicle or vehicles directly ahead.

**The CADS-IFM concept is to add infrastructure information securely communicated to the vehicles through V2I communications to enhance CACC capabilities. Details about CACC features that CADS-IFM will build on can be found in existing CACC documentation.**

CACC is a key enabling technology for multiple CADS use cases. One CADS use case involves improving freeway mobility through cooperative automation by supplementing CACC with V2I communications to potentially yield mobility, safety, and environmental benefits by reducing vehicle headway, smoothing traffic flow, and reducing the frequency of driver's longitudinal control errors. This use case is CADS-IFM.

This document describes the proposed CADS-IFM concept of adding infrastructure information securely communicated to the vehicles through V2I communications to further enhance CACC capabilities. Standard security credentials and protocols for V2I communications will be required for vehicles to use received infrastructure information to initiate CADS-IFM. Details about CACC features that CADS-IFM will build on and leverage can be found in existing CACC documentation.[1]

## 1.2 Purpose

The intent of this document is to articulate the first-generation CADS-IFM concept. Once finalized, this concept of operations (ConOps) document will be used to develop a series of functional requirements that map to specific operational concepts and will describe "what" the proposed system components would need to do, but not "how" they will do them.

The primary audience for this ConOps is CAMP and USDOT, while a secondary audience includes other stakeholders such as Infrastructure Owners and Operators (IOOs), other Original Equipment

[1] Cooperative Adaptive Cruise Control Small-Scale Test – Phase 1 Final Report. Intelligent Transportation Systems Joint Program Office, U.S. Department of Transportation. July 31, 2017. Performed by Crash Avoidance Metrics Partners LLC on behalf of the Vehicle-to-Infrastructure (V2I) Consortium.

Manufacturers (OEMs), and technology providers. This ConOps will help stakeholders envision the proposed system concept and begin planning, designing, and executing portions of the concept.

## *1.3 Document Overview*

The proposed system described herein documents concepts to extend CACC capability by establishing system objectives, operational concepts, identifying stakeholders, and documenting user needs. The organization of this document following this section are as follows:

- Section 2 describes stakeholders of the proposed system, as well as their challenges and needs.
- Section 3 describes goals and objectives for the proposed system, which are defined and mapped to overall challenges and user needs in Section 2.
- Section 4 describes the conditions of the proposed system and the stakeholders.
- Section 5 describes various operational concepts of the proposed system.
- Section 6 provides a glossary of terms.

# 2. Current Situation and Needs

## *2.1 Current System and Challenges*

Transportation demand on roadways in the United States generally continues (and is forecasted) to increase, given the simultaneous growth of the population, employment, and the economy, which all contribute to more personal travel and increasing freight flows of goods and services. At the same time, the highway infrastructure system in the United States has generally reached a mature state. The Interstate Highway System and supporting freeway network is generally built out, with new highway lane-miles and capacity expansion projects being relatively limited due to prohibitive costs.

Given increasing travel demand is outpacing highway capacity expansion, transportation agencies are generally shifting from a construction focus to a transportation system management and operations (TSMO) focus to increase highway capacity with operational improvements to maintain and even restore the performance of the existing transportation system before new construction needed. IOOs are increasingly deploying new technologies on the highway network to improve operations and help drivers make better decisions. Corresponding technologies are increasingly being developed, tested, and deployed for infrastructure and vehicles to collect, process, and securely exchange data for a variety of safety and mobility applications that leverage V2V or V2I communications or both.

ACC is an example of a vehicle enhancement that builds on traditional cruise control (CC) by adding sensing capabilities to automatically adjust vehicle speed based on the presence of a preceding vehicle that is immediately downstream. This feature has become an increasingly prevalent feature in vehicles. While ACC technologies help to improve safety and driver comfort over traditional CC, studies have shown that ACC has little effect on lane capacity, regardless of market penetrations, and even a stream of ACC vehicles may fail to achieve string stability, causing a negative impact on traffic capacity.[2,3]

Currently, a driver manually activates CC and sets a driving speed. Vehicles with additional sensing capabilities may have ACC and allow the driver to customize following distances. Vehicles with additional V2V capabilities may have CACC capabilities that allow for closer following distances when V2V messages are exchanged with vehicles in a CACC string. In general, any level of this CC functionality is typically overridden but still active when a driver accelerates, remains active as the driver changes lanes, and is deactivated when the driver presses the brake pedal. The driver typically receives a notification when CC is operational, on and deactivated, or not on; the customized driver following distances may also be displayed.

---

[2] Milanés, V., Shladover, S.E., 2014. *"Modeling cooperative and autonomous adaptive cruise control dynamic responses using experimental data*". Transportation Research Part C: Emerging Technologies 48, 285-300.

[3] https://www.automotiveworld.com/news-releases/tech-ford-vanderbilt-show-dont-wait-self-driving-cars-mitigate-phantom-traffic-jams/

## 2.2 Stakeholder Groups

Four stakeholder groups have been identified that will interact with and/or be impacted by the proposed system for CADS-IFM. All travelers are expected to experience increased mobility as a result of CADS-IFM, while other stakeholders will be responsible for operating and maintaining the new equipment and systems. Following is a list of the primary stakeholder groups who will most directly interact with CADS-IFM:

1. **Drivers in vehicles with CADS-IFM**. This primary end user of CADS-IFM includes passenger vehicle drivers who will have CACC and the CADS-IFM application on their vehicle. These drivers could activate CADS-IFM mode when driving on equipped lane segments of a freeway. Information received from secured V2I communications may adjust CACC speed and gap targets. Drivers will have an option to increase the CADS-IFM gap distances according to their preferences and comfort.

2. **Drivers in vehicles not using CADS-IFM**. This includes a range of roadway users that will not have the CADS-IFM application on their vehicle or choose to not use the CADS-IFM application, including passenger vehicle drivers, commercial drivers, vehicles towing trailers, transit vehicle operators, and motorcycle operators who travel on freeways where CADS-IFM will be deployed. Although these drivers will not interact directly with CADS-IFM, it is desirable for strings of CADS-IFM and CACC vehicles to have no negative impacts to safety or driver comfort.

3. **Vehicle Systems**. This includes all vehicles operating on freeways, which are organized below in order of increasing capabilities:

    - *Unequipped, manual vehicle systems*. These vehicle systems operate in manual mode and are fully controlled by the driver.

    - *Vehicle systems with traditional cruise control (CC).* These vehicle systems include traditional CC functions that allow the driver to select a speed for the system to then control the vehicle's acceleration and deceleration in order to maintain the speed set by the driver.

    - *Vehicle systems with Adaptive Cruise Control (ACC).* These vehicle systems are equipped with additional sensing capabilities that allow the system to control the vehicle's acceleration and deceleration by maintaining a fixed time gap to the preceding vehicle based on radar data. Drivers may set the target gap for following a vehicle, e.g. close, medium, far, according to their preference and comfort.

    - *Vehicle systems with CACC.* These vehicle systems are additionally equipped with V2V capabilities that allow for closer following distances. Specifically, the Vehicle System exchanges Basic Safety Messages (BSMs) and the BSM extensions for CACC, which include vehicle speed and trajectory information, using V2V communications. In the CACC state, the system controls the vehicle's acceleration and deceleration by maintaining a time gap to the preceding vehicle as well as other control strategies such as multi-vehicle look-ahead or single-vehicle look-ahead, which are considered sub-states of the CACC state. Whenever the system is transitioning into the CACC state, the one-vehicle look-ahead sub-state is always entered first. As soon as conditions for transition into the multi-vehicle look-ahead sub-state are met, the system performs that transition. While in the CACC state, the system transitions between the two sub-states based on the sub-state transitions requirements.

- *Vehicle systems with CADS-IFM.* These vehicles systems will operate with SAE Level 1 or Level 2 Automation with the basic CACC and lane keeping functions and will be additionally equipped with V2I capabilities and have the CADS-IFM application located within the vehicle. The CADS-IFM application will determine longitudinal movement controls for the vehicle to perform when it is active based on target speed and target time gap information received from the IOOs.

4. **Infrastructure Owner Operators**. This includes transportation agencies that are responsible for deploying roadside equipment to collect, process, and store data from the infrastructure and other vehicles to share with CADS-IFM vehicles in a Roadside Safety Message (RSM) using V2I communications. This includes data related to the target speed, target time gap, and messages describing merging vehicles from an adjacent on-ramps.

## *2.3 User Needs*

The following user needs have been identified for the proposed system of CADS-IFM:

- Need #1: IOOs and all drivers need all vehicles and roadway participants (both with or without CADS-IFM) to safely co-exist on the same road network, including at freeway off-ramps, freeway on-ramp merge points, within the same lanes on freeways, and when workers, emergency responders, or incident responders are present.
- Need #2: IOOs and all drivers need mobility to be maintained or improved as travel demand increases. Specifically, IOOs need to maintain or improve mobility parameters such as throughput, travel time, travel time reliability, and/or flow rate to support freeway travel.
- Need #3: Drivers in vehicles with CADS-IFM need to understand when their vehicle is operating in CADS-IFM mode, CACC/ACC/CC mode, or full manual control.
- Need #4: In order to operate in CADS-IFM mode, the vehicle system needs to securely receive a current target speed from IOOs for the highway on which the vehicle is traveling, with segment information to indicate the freeway segment for which the target speed applies. The target speed may be the posted speed limit or a target speed that is greater or less than the posted speed limit to increase throughput.
- Need #5: In order to operate in CADS-IFM mode, the vehicle system needs to securely receive a current target time gap from IOOs for the highway on which the vehicle is traveling, with segment information to indicate the freeway segment for which the target time gap applies.

- Need #6: The vehicle system needs to be aware of nearby downstream vehicles, as well as information regarding nearby vehicles operating in either CACC or CADS-IFM mode to form or join a CACC string of vehicles on an ad-hoc basis.

# 3. Proposed CADS-IFM Concept

Given the mobility challenges described in Section 2.1, the primary motivation for the development of CADS-IFM is to leverage available technologies to reduce freeway traffic congestion by improving highway and roadway capacity and throughput. While CACC builds on ACC systems by utilizing V2V communications, CADS-IFM adds V2I communications to further enhance CACC capabilities, as depicted in Figure 1. By advancing CACC capabilities, CADS-IFM may further reduce vehicle gaps to increase highway lane capacity and throughput. This will be accomplished through the utilization of IOO-provided information within RSMs regarding target speeds, target time gaps, and notices of merging vehicles. Secondary benefits of CADS-IFM may include improving safety, fuel efficiency, and driver comfort, although these are not the primary motivations for developing and testing the proposed system.

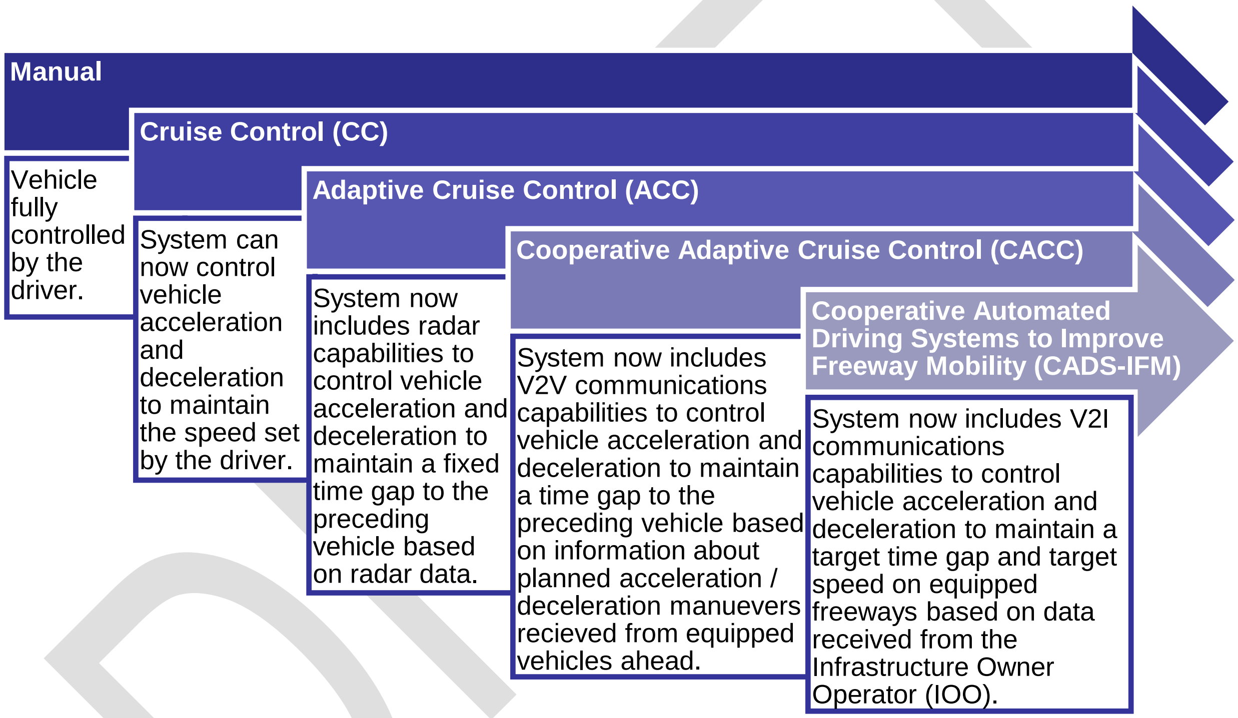


Figure 1. Depiction of vehicle systems that cumulatively increase cruise control capabilities.

## *3.1 Defining the First-Generation, CADS-IFM Concept*

As CADS-IFM builds on CC, ACC, and CACC system concepts, a larger CADS concept is envisioned to be developed over several generations. The proposed CADS-IFM system described herein is the first-generation CADS, identified as CADS-IFM, for specific freeway scenarios, that may be enhanced for additional roadways and managed lanes scenarios in the future. Likewise, CADS-IFM capabilities may be augmented as penetration rates increase available V2V information and increased deployments of IOO roadside equipment provides increased V2I information. Note that while some system information may be exchanged in BSMs on the “safety channel", additional details could be communicated via other channels or other means like cellular communications.

Some specific examples of how widespread deployment of a mature CADS-IFM may ultimately improve freeway mobility include the following.

- V2I communications could communicate IOO provided target speed and target time gap information to CADS-IFM equipped vehicles to support:
    - Lower vehicle headways;
    - Increased throughput;
    - Reducing delays and drive time; and
    - Potential improvements in fuel consumption and air quality.
- V2I communications could enable any vehicle merging into the freeway to be recognized by a string of CADS-IFM vehicles and allow them to adjust.
- V2I communications could communicate anomalies to CADS-IFM equipped vehicles, alerting them in advance of lane merges, hazardous weather conditions, obstructions in the road, work zones, incidents, or the presence of other vulnerable road users.

## *3.2 Goals of this Document*

The intent of this document is to describe the proposed CADS-IFM concept without reiterating details about the CACC/ACC/CC mode features that CADS-IFM will build on and leverage. The following goals have been identified for this document, which will advance the concept for developing the first generation of CADS-IFM to help address the challenges identified in Section 2.1.

- Goal #1: Define the CADS-IFM concept and related requirements in order that CAMP and USDOT can understand and agree with the overall concept.
- Goal #2: Define CADS-IFM approaches to external factors including lane merges, anomalies in the infrastructure, work zones, incidents, weather, and the presence of workers, first responders, law enforcement, and other vulnerable road users.
- Goal #3: Consider the role of speed harmonization, gap determination, and lane assignment to enable IOOs to improve mobility parameters such as throughput, travel time, travel time reliability, and/or traffic flow and generate initial functional concepts to be developed in future versions of CADS.

# 4 Conditions

The sections that follow provide a basic description of the underlying assumptions about the roadway environment and vehicle parameters that apply to all concepts and use cases described in this document. Note that the specific inclusion or exclusion of any roadway type or vehicle class, or description of any parameters for this document does not preclude changes being made at some future point to modify the proposed system.

## 4.1 Anticipated Roadway Conditions for the Proposed System

It is anticipated that CADS-IFM will be operated on restricted-access roadways having a minimum of two lanes in the direction of travel. CADS-IFM could be operated in urban or rural areas. Vehicles with CADS-IFM will travel together with mixed vehicles in both light and heavy traffic conditions. Vehicles with CADS-IFM will likely encounter situations with both light and heavy ingress traffic from on-ramps. The baseline scenario assumes clear, dry, smooth, and unobstructed conditions.

The CADS-IFM concept requires that CADS-IFM vehicles receive messages from the infrastructure. The RSM is referenced as the format for communicating messages. The primary communications technology will be short-range communications from the roadside to the vehicle, however other options such as cellular communications to the vehicle are possible.

The CADS-IFM concept anticipates that anomalies (i.e. deviations from the baseline that may impact vehicle performance, such as incidents, work zones, lane closure, and adverse weather conditions) may influence the IOOs to broadcast lower target speeds and/or larger target time gaps. Other IOO-provided information that directly articulates those anomalies may be consumed in other applications but will not influence the CADS-IFM mode operations.

CADS-IFM must have data about a target speed and target time gap from the IOO to function. This target speed may be the posted speed limit or a dynamic speed limit broadcasted by the IOO that is greater or less than the posted speed limit. Note that CADS-IFM assumes the target speed is consistent for all lanes that support CADS-IFM, and not a lane-level speed limit.

It is possible that CADS-IFM will not be supported for all freeway lanes. Vehicles will continue to operate in CADS-IFM mode when the driver changes from one lane to another if both lanes support CADS-IFM, however CADS-IFM mode will deactivate when the driver changes to a lane that does not support CADS-IFM. Additionally, for this first iteration, CADS-IFM will not be supported on interchanges.

## 4.2 Anticipated Vehicle Types and Conditions

This document assumes that the vehicles using CADS-IFM will typically be light duty passenger vehicles. Specifically, the largest vehicles that are envisioned to be equipped with CADS-IFM are long-wheel-based, full-size Sport Utility Vehicles (SUVs) that are not in towing mode. The proposed system would leverage existing vehicle radar / vision sensors supplemented with cooperative communication, and it is assumed that CADS-IFM is a vehicle-integrated control system that leverages available features and conditions to affect vehicle dynamics. Finally, CADS-IFM is proposed to be a driver-initiated system that would be classified as SAE Level 1 or Level 2 Automation, where the driver remains responsible for the safe operation of the vehicle.

Note that CADS-IFM is not intended for use in truck platooning, which is being developed separately for commercial vehicle use. Additionally, the first-generation system proposed in this document is not based on centralized command control of vehicles or string formation. Strings of equipped vehicles are formed on an ad-hoc basis.

CADS-IFM will build on CACC capabilities, as described in Section 2.1 and CACC documentation.[1] CADS-IFM is expected to incorporate a similar approach for activation, deactivation, driver notifications, and transitions between CACC/ACC/CC modes and to manual mode as current cruise control features. As such, this document describes the proposed CADS-IFM concept without reiterating details about the CACC/ACC/CC mode features that CADS-IFM will build on and leverage.

# 5 Operational Concepts

Operational concepts are provided below for four distinct perspectives reflecting the conditions presented in Section 4:

5.1 CADS-IFM Driver Perspective.
5.2 Non-CADS-IFM Driver Perspective.
5.3 CADS-IFM Vehicle System Perspective.
5.4 Infrastructure Owner-Operator Perspective.

## *5.1CADS-IFM Driver Perspective*

5.1.1 Drivers manually elect to enter CADS-IFM mode.

5.1.1.1 Drivers will perform an action to elect to enter CADS-IFM mode. This action will be similar to when drivers activate traditional CC, ACC, or CACC.

- CADS-IFM mode may automatically be powered on when other cruise control capabilities are powered on.

5.1.1.2 Upon selecting to enter CADS-IFM mode, the driver may notice that the vehicle immediately commences operations in CADS-IFM mode.

- The vehicle may immediately commence CADS-IFM mode if the road segment is CADS-IFM equipped and infrastructure information is available.

5.1.1.3 Upon selecting to enter CADS-IFM mode, the driver may notice that the vehicle immediately commences operations in CACC mode.

- The vehicle may immediately commence CACC mode if the road segment is not CADS-IFM equipped or if infrastructure information is not available.

5.1.1.4 Once the driver's vehicle begins operating in CADS-IFM mode, the driver may be provided some form of notification that CADS-IFM mode is active. This may be similar or in addition to the notification provided when traditional CC is active or when the driver's vehicle has joined one or more other vehicles in a CACC 'string'.

5.1.1.5 The driver will have no additional actions to initiate or sustain CADS-IFM mode until either the driver overrides or the vehicle systems automatically discontinue CADS-IFM mode, as described for the CADS-IFM driver perspective in 5.1.5 and 5.1.6.

5.1.2 CADS-IFM speed control.

5.1.2.1 While in CADS-IFM mode, the driver may notice the speed increasing or decreasing without their input in order to maintain the target time gap between the vehicle and the immediate downstream vehicle. This change in speed will be similar to when a vehicle operates in ACC or CACC mode and will accommodate normal influences such as changes in terrain or changes in the speed of the vehicle ahead.

5.1.2.2 The CADS-IFM driver may observe their vehicle traveling at speeds that are above, at, or below the speed limit for manually driven vehicles as the vehicle adjusts its speed to maintain the IOO-provided target speed and IOO target time gap for a section of roadway within a design margin. Examples of conditions when the IOO target speed may decrease include:

- IOO target speed reduction as a result of horizontal or vertical curves, congestion, incidents, queue warning, or other conditions.
- IOO target speed reduction as a result of environmental conditions, such as adverse road weather conditions.

5.1.2.3 The CADS-IFM driver may observe their vehicle slowing or stopping to avoid obstacles and not relying solely on IOO target speeds. The vehicle may remain in CADS-IFM mode when it slows down to avoid an obstacle. Observed changes in speed may occur for a variety of conditions, including:

- A downstream vehicle increases or decreases its speed, requiring following vehicles to make adjustments to maintain the desired gap.
- Adjustments to create a downstream gap to allow a vehicle to merge onto the highway, regardless of whether the merging vehicle has V2V communications.
- Adjustments to close a downstream gap in the CACC string after a vehicle exits the string.

5.1.2.4 CADS-IFM operates at SAE Level 1 or Level 2 Automation such that the driver is always responsible for the safe operation of the vehicle, with the ability to override or exit CADS-IFM mode at any time, although CADS-IFM does not require driver input to increase or decrease speed based on IOO-provided recommendations and to avoid downstream obstacles, e.g. downstream vehicles.

5.1.3 Following other vehicles in CADS-IFM and CACC string formation.

5.1.3.1 The driver may observe the vehicle operating in CADS-IFM mode as an individual vehicle or as part of a CACC ‘string’ with other vehicles.

5.1.3.2 The driver may observe the vehicle approaching and establishing a following distance behind another vehicle, which is done in CADS-IFM using the same protocols established for CACC mode.

5.1.3.3 The driver may observe that the gap between the preceding vehicle is different than the gap while in CACC mode, as the CADS-IFM vehicle will receive a target time gap from the IOO and adjust to meet this gap.

5.1.4 Driver CADS-IFM gap control.

5.1.4.1 The driver may choose to increase the time gap to be longer than the target time gap received from the infrastructure and remain in CADS-IFM mode.

- The driver may increase the time gap based on personal preference or comfort level in the current driving conditions.

5.1.4.2 The driver will not have the option to decrease the time gap to be shorter than the target time gap received from the infrastructure while engaged in CAD-IFM mode.

5.1.5 Status change from CADS-IFM mode by the application.

5.1.5.1 At times, the driver will experience the vehicle exiting CADS-IFM mode and entering CACC/ACC/CC mode or manual mode without the driver requesting a state change.

5.1.5.2 The driver may be presented a notification that the vehicle is now operating in CACC/ACC/CC mode or manual mode.

5.1.5.3 Situations that could require transition to CACC mode when CADS-IFM mode is deactivated by the application are depicted in Table 1 and include:

- The vehicle is no longer traveling on a roadway supported with the V2I communications needed for CADS-IFM.
- Failure of infrastructure communications.

5.1.5.4 The driver would be required to take over if CADS-IFM mode is deactivated by the application and reverts to manual mode given a failure of the forward obstacle detection system, as depicted in Table 1.

5.1.6 Status change from CADS-IFM mode by the driver.

5.1.6.1 The driver may opt to deactivate or override CADS-IFM mode in a variety of ways for any reason as depicted in Table 1, including:

- Driver manually turns CADS-IFM off, which *deactivates* CADS-IFM mode.
- The driver applies the brakes, which causes the vehicle to respond, slow down, and *deactivate* CADS-IFM mode. The vehicle will be in manual mode and the driver would be required to re-engage CADS-IFM.
- The driver accelerates by pressing the accelerator pedal or controls and the vehicle responds to the throttle, which *temporarily overrides* the CADS-IFM function. The vehicle will return to CADS-IFM mode after the driver releases the throttle if all necessary conditions are met.
- The driver manually navigates the vehicle to change lanes to a lane that does not support CADS-IFM, which *passively deactivates* CADS-IFM mode to CACC/ACC/CC mode.
- The driver manually navigates to exit the freeway or travels to a freeway segment without the V2I communications needed to support CADS-IFM, which *passively deactivates* CADS-IFM mode to CACC/ACC/CC mode.

Table 1. Matrix showing the possible transitions from one driving mode to another.

| | | END STATE | | |
|---|---|---|---|---|
| | | **Manual** | **CC / ACC / CACC[1]** | **CADS-IFM** |
| **CURRENT STATE** | **Manual** | | One of the following:<br>a) Driver activation of CACC/ACC/CC; or<br>b) Driver activation of CADS-IFM on freeway segment without supporting IOO information | Driver activation of CADS-IFM on freeway segment with supporting IOO information |
| | **CC / ACC / CACC[1]** | One of the following[2]:<br>a) Brake activation<br>b) Driver presses accelerator pedal (temporary override)<br>c) Driver system deactivation<br>d) Failure of forward object detection system | | One of the following:<br>a) Driver activation of CADS-IFM with supporting infrastructure<br>b) CADS-IFM already activated and vehicle enters freeway segment with supporting IOO information |
| | **CADS-IFM** | One of the following[2]:<br>a) Brake activation<br>b) Driver presses accelerator pedal (temporary override)<br>c) Driver system deactivation<br>d) Failure of forward object detection system | One of the following:<br>a) Vehicle no longer traveling on a freeway or freeway lane with supporting IOO information<br>b) Failure of Infrastructure communications | |

[1] See CACC ConOps for details of state changes

[2]Transition to manual mode will be supported by CACC Manual Recovery State, as described in the CACC ConOps. The purpose of Manual Recovery State is to ensure that the time gap supports controllable driver operation before transitioning to Manual state

## 5.2 Non-CADS-IFM Driver Perspective

5.2.1 General driving experience.

5.2.1.1 Drivers in a vehicle that does not have CADS-IFM or does not have CADS-IFM activated will operate their vehicle as they do now.

5.2.1.2 Non-CADS-IFM drivers traveling in their vehicle down a freeway will observe strings of vehicles that are similar to strings of vehicles observed today, except that strings of vehicles that use CACC and CADS-IFM will likely be traveling with smaller gaps between vehicles than manually driven strings.

5.2.1.3 Non-CADS-IFM drivers traveling in their vehicle down a freeway may attempt to merge into an adjacent lane, e.g. to exit the freeway. In situations where a CADS-IFM or CACC string of vehicles occupies the adjacent lane, the small gaps may not allow a space for the vehicle to safely or easily merge. Depending on the circumstances and determinations of individual vehicles in the string, a gap may or may not open to allow the driver of the non-CADS-IFM vehicle to merge.

5.2.2 Merging onto a freeway.

5.2.2.1 All drivers merging onto a freeway will be operating as non-CADS-IFM vehicles because the CADS-IFM functionality would not begin until the vehicle is operating on the freeway.

5.2.2.2 Non-CADS-IFM drivers traveling in their vehicle on a freeway on-ramp will attempt to merge onto the adjacent freeway lane. In situations where a CADS-IFM strings of vehicles occupies the adjacent freeway lane, the small gaps may not always allow a space for the non-CADS-IFM vehicle to merge, and the non-CADS-IFM driver will have to make adjustments in speed in order to merge ahead of or behind the vehicle string as they do in today's operations.

5.2.2.3 Non-CADS-IFM drivers actively merging onto the freeway may observe a gap form in a string of vehicles if one or more vehicles are in CADS-IFM mode and the vehicle receives a message from the infrastructure indicating that a vehicle is merging.

## 5.3 CADS-IFM Vehicle System Perspective

5.3.1 CADS-IFM activation.

5.3.1.1 CADS-IFM will activate only after a driver selects CADS-IFM mode on a vehicle.

5.3.1.2 After CADS-IFM mode is activated, CADS-IFM will initially operate in the background and defer to CACC mode, pending receipt of V2I messages.

5.3.1.3 CADS-IFM vehicle systems will engage CADS-IFM mode only upon receipt of V2I communications from the IOO to include, at a minimum:

- The target speed for the highway on which the vehicle is traveling. This may be greater or less than the posted speed limit.
- The target time gap for the highway on which the vehicle is traveling.
- Segment details to indicate the freeway segment for which the target speed and target time gap apply.

5.3.1.4 Once CADS-IFM is activated, the vehicle will provide an indication that it is operating in CADS-IFM mode in the BSM transmitted by the vehicle.

5.3.2 CADS-IFM use of V2V communications.

5.3.2.1 CADS-IFM builds on CACC, with no changes in how V2V communications are used by CACC. Specifically, receiving and processing BSMs from other vehicles that will include their latitude/longitude, acceleration or deceleration, and heading to support the formation of ad-hoc CACC vehicle strings.

5.3.2.2 CADS-IFM will utilize security measures for all broadcast and processed BSMs, as done in CACC.

5.3.3 CADS-IFM use of V2I communications.

5.3.3.1 CADS-IFM will only operate with receipt of V2I messages containing IOO-provided target speed and target time gap information.

5.3.3.2 CADS-IFM may receive V2I messages that describe merging vehicles at downstream freeway interchanges that could prompt the string of CADS-IFM vehicles to create a gap that would allow the non-CADS-IFM vehicle to merge.

5.3.3.3 CADS-IFM will receive V2I messages with IOO recommendations (i.e. target speed and target time gap) for a given segment.

- The vehicle system will process the segment description received and compare it to the vehicle position to determine which segment the vehicle is operating in.

5.3.3.4 CADS-IFM will only process V2I messages that meet expected security protocols.

5.3.3.5 A vehicle operating in CADS-IFM mode will use V2I communications to broadcast data elements describing CADS-IFM operations.

- Vehicles will provide an indication they are operating in CADS-IFM mode in the BSM transmitted by the vehicle.
- Vehicles may broadcast messages about the actual time gap established for the vehicle (i.e. to enable IOOs to compare target time gap sent to vehicles with actual time gaps set by vehicles). Note that if implemented, this would be in BSM Part 2, but this is not supported by BSM Part 2 today.

5.3.4 General CADS-IFM operation.

5.3.4.1 CADS-IFM will utilize CACC mode to form strings on an ad-hoc basis and make adjustments in speed to maintain the target time gap with the immediately preceding vehicle.

5.3.4.2 CADS-IFM vehicles will use V2I information from IOOs to enhance CACC capabilities and operate at the target speed communicated by IOOs through V2I messages.

- When a CADS-IFM vehicle approaches a location on the roadway with a change in the target speed, the vehicle's speed will automatically adjust.
- If a CADS-IFM vehicle is in a string following a vehicle when it receives an IOO-provided speed reduction and the vehicle it is following does not slow to the IOO-provided target speed, the CADS-IFM vehicle will slow to the target speed causing it to separate from the immediately preceding vehicle.
- If a CADS-IFM vehicle is in a string following a vehicle when it receives an IOO-provided target speed increase and the vehicle it is following does not increase the speed to match the target speed, the CADS-IFM vehicle will maintain the target time gap (i.e. remain at a speed that is below the target speed).

5.3.4.3 CADS-IFM will use V2I information from IOOs to enhance CACC capabilities in determining the time gap if it is a following vehicle. Several assumptions or considerations to be made for CADS-IFM development include:

- IOOs will provide a target time gap. This may be a default target time gap for the segment, or a gap value that changes based on current conditions.
- Vehicles operating in CADS-IFM mode will adjust their speeds to adapt to and maintain the target time gap received by the IOOs.
- The driver will have the option to increase the time gap above the IOO-provided target time gap based on comfort level preferences. The driver may also override CADS-IFM and opt out to manually control the time gap.

5.3.4.4 CADS-IFM may make adjustments in speed of the vehicle (without exceeding the recommended speed provided by the IOO) to allow a gap for a vehicle to merge from an on-ramp based on information received from the IOO. This IOO-provided information could be about any merging vehicle and not require ramp metering capabilities.

- Adjustments to the speed of the CADS-IFM vehicle would be made based on its relative position to the merging vehicle.
- Future enhancements of CADS-IFM may allow adjustments in speed to allow another vehicle to merge based on BSM data received from the vehicle merging from either an adjacent lane or on-ramp.

5.3.5 CADS-IFM deactivation.

5.3.5.1 CADS-IFM mode may be deactivated by the driver at any time.

5.3.5.2 CADS-IFM mode may automatically deactivate under a variety of possible circumstances. Failure of infrastructure communications, for example, could cause

CADS-IFM to automatically deactivate and revert to CACC/ACC/CC mode or manual mode depending on operating conditions.

5.3.5.3 The vehicle system may provide a notification to the driver when CADS-IFM is automatically deactivated.

5.3.5.4 When CADS mode is deactivated, CADS-IFM will cease transmitting CADS-IFM specific data or processing data from other vehicles for CADS-IFM.

## *5.4 Infrastructure Owner-Operator Perspective*

5.4.1 IOO provided data.

5.4.1.1 For the purposes of CADS-IFM, IOOs will determine and provide a target speed that applies to a specified segment along the freeway. This target speed will apply to all CADS-IFM enabled lanes of the roadway for equipped corridors.

- The target speed may be a static value that is greater than or equal to the posted speed limit established for manually driven vehicles.
- The target speed may be lower than the posted speed limit, based on current conditions (e.g. to slow all traffic and maintain a consistent speed through congestion, to slow traffic in advance of inclement weather or obstructions on the roadway, etc.).
- The target speed will be included in the RSM.

5.4.1.2 For the purposes of CADS-IFM, IOOs will determine and provide a target time gap that applies to a specified segment along the freeway.[4]

- The target time gap may be a fixed value.
- The target time gap may be a dynamic value that differs based on current conditions (e.g. to maintain wider gaps during inclement weather conditions).
- The target time gap may be lower than the minimum time gap established for manually driven vehicles.
- The target time gap will be included in the RSM.

5.4.1.3 The segments that describe the target speed and time gap may vary in length (e.g. may be small to describe the area around a freeway interchange or may be long for stretches of highway with consistent characteristics).

- Segments may be predefined static segments.
- Segments may be dynamically created, changed, or combined.
- A future enhancement of CADS-IFM may include segments for on-ramps or freeway-to-freeway interchanges.

[4] Discussion is needed with the IOOs to determine whether national consistency is required for IOOs to establish these parameters.

5.4.1.4 IOOs may also provide information regarding road weather, work zone, incident, congestion, or other downstream conditions.

- This information will not impact the CADS-IFM application, unless the IOO adjusts the target speed or time gap.

5.4.1.5 In areas near freeway interchanges, the IOO may detect vehicles entering the CADS-IFM equipped lane from on-ramps and create an RSM message to communicate this information to approaching CADS-IFM vehicles.

5.4.2 Roadside equipment.

5.4.2.1 The IOO will broadcast RSMs that contain both a target speed and a target time gap for specified segments.

- Roadside equipment broadcasting RSMs is the primary communication method for target speed and target time gap as all CADS-IFM vehicles will have the capability to receive RSMs.
- Target speed and target time gap information does not require extremely low latency communications, therefore wide-area communications mediums (e.g. cellular or satellite) may be optional methods for communicating target speed and target time gap information, if all CADS-IFM vehicles were able to support the communications method.

5.4.2.2 The IOO may broadcast RSMs to describe when vehicles are on the on-ramp and will be merging with the freeway traffic.

5.4.2.3 Roadside equipment may receive BSMs and other data from passing vehicles, including equipped vehicles with CADS-IFM.

5.4.3 Future ramp meter enhancements.

5.4.3.1 A future enhancement of CADS-IFM may allow IOO roadside equipment to make adjustments to ramp metering based on awareness of a string of CADS-IFM vehicles approaching an merge point, in order to minimize disruptions to the CADS-IFM string.

# 6 Glossary

| | |
|---|---|
| ACC | Adaptive Cruise Control – A Level 1 automation system that longitudinally controls a vehicle based on a set speed and distance to the preceding vehicle using sensor systems such as radar or vision for the detection of preceding vehicle(s). Strings of ACC vehicles form “ad-hoc” and car following is based on a constant time gap strategy. |
| BSM | Basic Safety Message – A standard SAE-defined message communicated from equipped vehicles containing data elements that include, for example, vehicle location and acceleration. |
| CACC | Cooperative Adaptive Cruise Control – A system that extends ACC through the use of communication between the vehicles. |
| CADS | Cooperative Automated Driving Systems – A suite of extensions to CACC that use vehicle-to-infrastructure (V2I) communications with the infrastructure owner operator (IOO) in addition to vehicle-to-vehicle (V2V) communications between vehicles. |
| CADS-IFM | Cooperative Automated Driving Systems to Improve Freeway Mobility – An SAE Level 1 or Level 2 Automation system that extends CACC through the use of vehicle-to-infrastructure (V2I) communications with the infrastructure owner operator (IOO) on equipped freeways in addition to vehicle-to-vehicle (V2V) communications between vehicles. |
| CC | Cruise Control – A longitudinal control system that operates solely based on maintaining a driver set speed. |
| IOO | Infrastructure Owner Operator – The public or private agency that owns, operates, and/or maintains the roadway and is responsible for providing infrastructure-related data via roadside safety messages (RSMs). |
| Posted Speed Limit | The speed limit established by the IOO for manually driven vehicles on a roadway segment provided to drivers by static signage or via dynamic message signs. |
| Preceding (vehicle) | The vehicle immediately downstream of the specified vehicle. |
| RSM | Roadside Safety Message – A standard message communicated to equipped vehicles from the IOO containing data elements such as target speed and target time gap. |
| Segment | Freeway lane(s) defined by upstream and downstream points between which the target speed and target time gap information provided by the infrastructure owner operator (IOO) applies. |

| | |
|---|---|
| Target Speed | A data element provided in the RSM by IOO for a road segment based on current conditions. The target speed will identify the desired vehicle speed established by the IOO for a freeway segment and may be greater, equal to, or less than the posted speed limit. |
| Target Time Gap | A data element provided in the RSM by the IOO for a freeway segment based on current conditions. The target time gap will identify the desired time gap established by the IOO for a freeway segment. The target time gap may be lower than that established for manually driven vehicles. |
| Time Gap | The time that the host vehicle would need at its current speed to travel the clearance distance with the preceding vehicle. |
| V2I Communications | Communications capability enabling vehicles and infrastructure to exchange messages, such as the Roadside Safety Message (RSM), between the infrastructure owner operator (IOO) and vehicles using cellular or dedicated short-range communications (DSRC), for example. |
| V2V Communications | Communications capability enabling vehicles to exchange messages, such as the Basic Safety Message (BSM), between vehicles using cellular or dedicated short-range communications (DSRC), for example. |