Improve Freeway Mobility (IFM) Using Cooperative Automation

High-Level Requirements

Draft Version 1.0

Revision History

Version	Date	Change Description	Affected Sections/Pages
0.5	05/09/2019	Internal Document	-
1.0	07/08/2019	First version confirmed by project team. .pdf version created (for use by non-project team)	Entire document Incorporates project team changes thru 30 June 2019

1. Introduction

1.1 Background

This document presents High-Level Requirements to Improve Freeway Mobility (IFM) using Cooperative Automation, 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. This document builds on the IFM Concept of Operations, with traceability to the operational concepts in that document.

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

CACC is a key enabling technology for multiple use cases. One 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 IFM.

This document describes the proposed IFM High-Level Requirements for adding infrastructure information securely communicated to the vehicles through V2I communications to further enhance CACC capabilities. Note that previous documentation has referred to this concept as Cooperative Automated Driving Systems to Improve Freeway Mobility (CADS-IFM). Additional details about CACC features that IFM will build on and leverage can be found in existing CACC documentation.[1] Standard security credentials and protocols for V2I communications will be required for vehicles to use received infrastructure information to initiate IFM.

1.2 Purpose

The intent of this document is to articulate the first-generation IFM High-Level Requirements that map to specific operational concepts for IFM in the Concept of Operations. Once finalized, these High-Level Requirements will be used as a basis for generating more detailed functional

[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.

requirements. These High-Level Requirements describe “what” the proposed system components would need to do, but not “how” they will do them.

The primary audience for these High-Level Requirements is CAMP and USDOT, while a secondary audience includes other stakeholders such as Infrastructure Owners and Operators (IOOs), other Original Equipment Manufacturers (OEMs), and technology providers. These High-Level Requirements will help stakeholders envision the proposed system concept and begin planning, designing, and executing portions of the concept.

1.3 Document Overview

The proposed high-level requirements described herein document an IFM system to extend CACC capability. The organization of this document following this section are as follows:

- Section 2 describes High-Level Vehicle Requirements, including the Driver Interface, Communications for Broadcast and Receipt, and Control.
- Section 3 describes High-Level Infrastructure Requirements, including the Information Broadcast and Information Receipt.
- Section 4 provides a glossary of terms.

The diagram in Figure 1 below illustrates the functions representing the groups of requirements presented in Section 2 and Section 3 for the IFM Vehicle and Infrastructure, respectively.

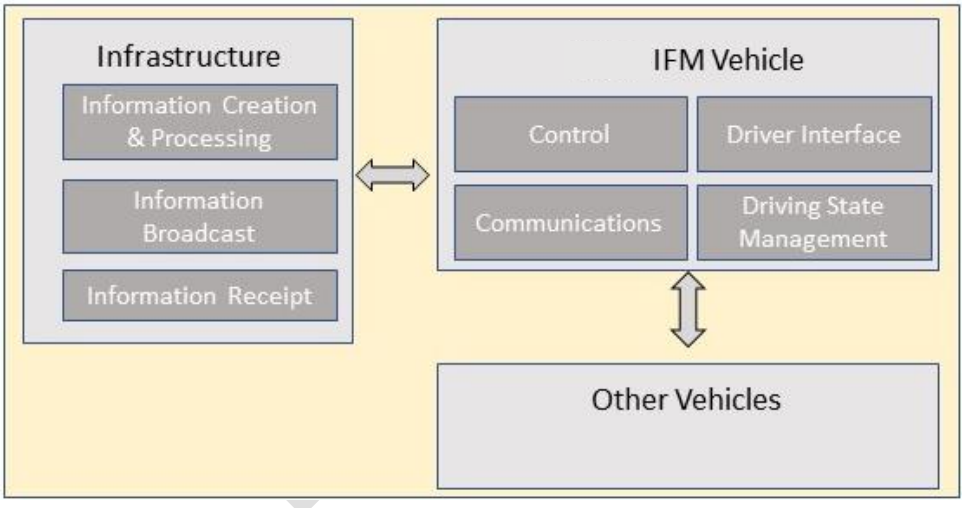

Figure 1. Diagram of IFM Vehicle and Infrastructure Function Groups for Requirements.

2. High-Level Vehicle Requirements

The High-Level Vehicle Requirements described in Table 1 build on those already included in CACC and describe requirements for an IFM-equipped vehicle to receive and use IOO-provided target time gap and target speed information provided via V2I communications. Table 1 links each High-Level Vehicle Requirement to an Operational Concept presented in the IFM Concept of Operations. Table 2 is provided to help illustrate possible transitions from one driving state to another, as described in several of the High-Level Vehicle Requirements.

Table 1. High-Level Vehicle System Requirements

High-Level Vehicle System Requirement	Operational Concept
2.1 Driver Interface Requirements	
2.1.1 IFM vehicles shall have an interface that allows a driver to perform an action to request to activate IFM mode, similar to when drivers activate traditional CC, ACC, or CACC.	5.1.1.1; 5.3.1.1
2.1.2 IFM vehicles shall require no driver actions to sustain IFM mode until either the driver overrides, or the vehicle systems automatically discontinue IFM mode.	5.1.1.5
2.1.3 IFM vehicles shall have an interface that allows a driver to increase the time gap to be longer than the target time gap received from the infrastructure and remain in IFM mode based on comfort level in the current driving conditions.	5.1.4.1; 5.3.4.3
2.1.4 The IFM vehicle interface shall not allow drivers to decrease the time gap to be shorter than the target time gap received from the infrastructure while engaged in CAD-IFM mode.	5.1.4.2
2.1.5 IFM vehicles shall have an interface that allows the driver to manually override or exit IFM mode at any time. (See Table 2.)	5.1.2.4; 5.1.6.1; 5.3.5.1
2.1.6 IFM vehicles shall deactivate IFM mode when the driver applies the brakes.	5.1.6.1
2.1.7 IFM vehicles shall allow drivers to temporarily override the IFM function by pressing the accelerator pedal or controls, causing the vehicle to respond to the throttle by accelerating. (See Table 2.)	5.1.6.1
2.2 Communications Requirements	
2.2.1 IFM vehicles shall have the capability to receive Road Safety Messages (RSMs).	5.4.2.1
2.2.2 Vehicles shall receive and process RSMs from the IOO for the highway on which the vehicle is traveling and determine whether both a target speed and target time gap have been received.	5.3.1.3; 5.3.3.1; 5.3.3.3
2.2.3 Vehicles shall receive and process RSMs from the IOO and process segment details that indicate the freeway segment for which the target speed and target time gap apply.	5.3.1.3; 5.3.3.3
2.2.4 Vehicles operating in IFM mode shall provide an indication that the vehicle is operating in IFM mode in the BSM transmitted by the vehicle.	5.3.1.4; 5.3.3.5

High-Level Vehicle System Requirement	Operational Concept
2.2.5 Vehicles operating in IFM mode may provide an indication about the actual time gap being used while operating in IFM mode in the BSM Part 2 transmitted by the vehicle.	5.3.3.5
2.2.6 IFM shall build on CACC, with no changes in V2V communications or security measures that are used by CACC.	5.3.2.1; 5.3.2.2
2.2.7 Vehicles shall only transmit IFM specific data when IFM is activated.	5.3.5.4
2.3 Control Requirements	
2.3.1 Vehicles shall only operate in IFM mode when operating on equipped freeway segments and freeway-to-freeway ramps. IFM will not be functional for on-ramps to or from arterial roadways.	5.2.2.1
2.3.2 Vehicles shall only operate in IFM mode when they are receiving and processing valid target speed messages from the IOO for the highway on which the vehicle is traveling.	5.3.1.3; 5.3.3.1; 5.3.3.3
2.3.3 Vehicles shall only operate in IFM mode when they are receiving and processing valid target time gap messages received from the IOO for the highway on which the vehicle is traveling.	5.1.3.3; 5.3.1.3; 5.3.3.1; 5.3.3.3
2.3.4 Vehicles shall only operate in IFM mode when they are receiving and processing valid segment details that indicate the freeway segment for which the target speed and target time gap apply.	5.3.1.3; 5.3.3.3
2.3.5 IFM shall continuously monitor the real-time latitude and longitude of the vehicle to compare it with the processed segment description received from the IOO to determine which segment the vehicle is operating in.	5.3.3.3
2.3.6 IFM vehicles shall operate using the target speed and target time gap information received from the IOO that applies to the freeway lane and segment it is currently traveling in.	5.3.3.3
2.3.7 IFM shall only process V2I messages that meet expected security protocols.	5.3.3.4
2.3.8 Vehicles operating in IFM mode shall approach and establish a following distance behind another vehicle using the same protocols established for CACC mode.	5.1.3.2
2.3.9 Vehicles operating in IFM mode shall adjust to meet the target time gap provided by the IOO, which may be different than the gap in CACC mode.	5.1.4.3
2.3.10 IFM vehicles shall override the IOO-provided target time gap when the driver selects an increased time gap based on comfort level in the current driving conditions.	5.1.4.1; 5.3.4.3
2.3.12 Vehicles operating in IFM mode shall automatically maintain the target time gap between the vehicle and the immediately preceding vehicle by adjusting speeds (i.e. accelerating or decelerating) without driver input. IFM uses CACC capabilities to accomplish this and accommodate normal influences such as changes in terrain or changes in the speed of the vehicle ahead.	5.1.2.1; 5.3.4.1; 5.3.4.3

High-Level Vehicle System Requirement	Operational Concept
2.3.13 Vehicles operating in IFM mode shall automatically adjust speed to maintain the IOO-provided target speed and time gap for the road segment, unless the vehicle detects a preceding vehicle or object that requires the vehicle to stop or slow.	5.1.2.2; 5.1.2.4
2.3.14 Vehicles operating in IFM mode shall automatically adjust the vehicle's speed in order to adhere to the target speed and target time gap for the freeway segment, which may be different from the target speed and target time gap of adjacent segments , unless a preceding vehicle or object requires the vehicle to travel at a slower speed.	5.3.4.2
2.3.15 Vehicles operating in IFM mode shall adjust to the target speed upon receiving a reduction in vehicle speed from the IOO, regardless of what actions are taken by the vehicle it is following (e.g. vehicles will break from a string with a downstream vehicle if that vehicle does not slow.	5.3.4.2
2.3.16 Vehicles operating in IFM mode shall maintain the target time gap with the vehicle it is following when it receives an IOO-provided speed increase and the vehicle it is following does not speed up to the IOO-provided target speed, i.e. the vehicle operating in IFM mode shall continue to follow the vehicle to remain at a speed that is below the target speed.	5.3.4.2
2.3.17 Vehicles operating in IFM mode shall automatically slow or stop to avoid obstacles, regardless of the IOO target speed, e.g. a downstream vehicle merges in front of the IFM vehicle or is operating at a slower speed, requiring the IFM vehicle to make adjustments to the time gap.	5.1.2.3; 5.1.2.4; 5.3.4.4
2.3.18 Vehicles operating in IFM mode may reduce speed and increase the time gap with the preceding vehicle if the vehicle receives a message from the infrastructure indicating that a vehicle is merging.	5.2.2.3; 5.3.3.2
2.4 Driving State Management Requirements	
2.4.1 IFM shall activate only after a driver selects to activate IFM mode on a vehicle. (See Table 2.)	5.3.1.1
2.4.2 Vehicles shall operate in CACC mode when IFM is activated whenever the required IOO information is not available or when traveling on a road segment that is not IFM equipped.	5.1.1.3; 5.3.1.2; 5.3.4.2; 5.3.4.3
2.4.3 IFM vehicles shall operate in IFM mode only with receipt of V2I communications from the IOO.	5.3.1.3; 5.3.3.1; 5.3.3.3
2.4.4 IFM vehicles shall operate in manual mode when drivers manually accelerates temporarily overrides IFM.	5.1.6.1
2.4.5 In IFM override mode, when the driver releases the accelerator, IFM vehicles shall return to IFM mode, if all necessary conditions are met.	5.1.6.1
2.4.6 Vehicles operating in IFM mode shall remain in IFM mode when the vehicle slows down to avoid an obstacle without driver intervention.	5.1.2.3

High-Level Vehicle System Requirement	Operational Concept
2.4.7 IFM vehicles shall deactivate IFM mode to CACC/ACC/CC mode when a driver manually navigates the vehicle to a lane that does not support IFM. (See Table 2.)	5.1.5.1; 5.1.5.3; 5.1.6.1
2.4.8 IFM vehicles shall deactivate IFM mode to CACC/ACC/CC mode when a driver manually navigates the vehicle to exit the freeway or travels to a freeway segment without the V2I communications needed to support IFM. (See Table 2.)	5.1.5.1; 5.1.5.3; 5.1.6.1
2.4.9 IFM vehicles shall transition to manual mode when drivers apply the brakes and IFM deactivates (i.e. not CACC mode).	
2.4.10 IFM mode shall revert to CACC/ACC/CC mode given the failure of infrastructure communications., for example, could cause IFM to automatically deactivate and manual mode depending on operating conditions (See Table 2.)	5.1.5.1; 5.1.5.3; 5.3.5.2
2.4.11 IFM mode shall revert to manual mode supported by CACC Manual Recovery State given the failure of the forward object detection system. (See Table 2.)	5.1.5.1; 5.1.5.4; 5.3.5.2

Table 2. Matrix showing the possible transitions from one driving state to another.

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

3. High-Level Infrastructure Requirements

As described in the IFM Concept of Operations, the proposed IFM system is for specific freeway scenarios and the first-generation IFM. IFM capabilities may be augmented as penetration rates increase available V2V information and increased deployments of IOO roadside equipment provides increased V2I information. For this first generation, V2I communications are needed for IOOs to provide target speed and target time gap information to IFM equipped vehicles. Additionally, V2I communications could enable any vehicle merging into the freeway to be recognized by a string of IFM vehicles and allow them to adjust in this first-generation system.

High-Level Infrastructure Requirements to support this IFM system are presented in Table 3 below. Additionally, each High-Level Infrastructure Requirement in Table 3 is linked to an Operational Concept presented in the IFM Concept of Operations.

Table 3. High-Level Infrastructure System Requirements

High-Level Infrastructure System Requirement	Operational Concept
3.1 Information Creation and Processing Requirements	
3.1.1 The IOO shall determine a target speed that applies to a specified segment along the freeway.	5.3.1.3; 5.3.3.1; 5.3.4.2; 5.4.1.1; 5.4.2.1
3.1.2 The IOO shall determine a target time gap that applies to a specified segment along the freeway.	5.1.3.3; 5.3.1.3; 5.3.3.1; 5.3.4.3; 5.4.1.2; 5.4.2.1
3.1.3 The IOO may adjust the provided target speed and/or target time gap for a segment as a result of horizontal or vertical curves, congestion, incidents, queue warning, environmental conditions such as adverse road weather conditions, or other conditions.	5.1.1.2
3.1.4 The IOO shall determine begin and end points or geographic boundaries and whether all or selected freeway lanes will be enabled for IFM to define a segment for which provided target speed and target time gap information apply.	5.3.1.3; 5.3.4.2; 5.3.4.3; 5.4.1.1; 5.4.1.2; 5.4.2.1
3.1.5 The IOO may detect vehicles entering the IFM equipped lane from on-ramps when providing information about merging vehicles to IFM vehicles is desired.	5.3.3.2; 5.3.4.4; 5.4.1.5
3.2 Information Broadcast Requirements	
3.2.1 The IOO shall broadcast a target speed that applies to a specified segment along the freeway.	5.3.1.3; 5.3.3.1; 5.3.4.2; 5.4.1.1; 5.4.2.1
3.2.2 The IOO-provided target speed shall apply to all IFM enabled lanes of the roadway for equipped corridors.	5.4.1.1
3.2.3 The IOO shall broadcast a target time gap that applies to a specified segment along the freeway.	5.1.3.3; 5.3.1.3; 5.3.3.1; 5.3.4.3; 5.4.1.2; 5.4.2.1
3.2.4 The IOO shall broadcast information to describe segments for which the provided target speed and target time gap apply. Segments may vary in length and either be predefined static segments or dynamically created, changed, or combined.	5.4.1.3; 5.4.2.1
3.2.5 The IOO may broadcast information about vehicles entering the IFM equipped lane from on-ramps in areas near freeway interchanges, as desired and available.	5.3.3.2; 5.3.4.4; 5.4.1.5; 5.4.2.2
3.2.6 The IOO shall broadcast information for IFM in RSMs.	5.4.1.1; 5.4.1.2; 5.4.1.3; 5.4.1.5; 5.4.2.1; 5.4.2.2
3.2.7 The IOO shall broadcast V2I messages using expected security protocols.	5.3.3.4
3.3 Requirements for Information Receipt	
3.3.1 IOO roadside equipment shall receive the BSM and BSM Part 2 from passing vehicles when the IOO wishes to monitor vehicle data.	5.3.1.4; 5.3.3.5; 5.4.2.3

High-Level Infrastructure System Requirement	Operational Concept
3.3.2 The IOO shall process received information in BSM Part 2 when the IOO wishes to understand the number of vehicles operating in IFM mode.	5.3.3.5; 5.4.2.3
3.3.3 The IOO shall process received BSM Part 2 messages when the IOO wishes to compare target time gap sent to vehicles with actual time gaps used by IFM vehicles.	5.3.3.5; 5.4.2.3
3.3.4 The IOO may detect vehicles entering the IFM equipped lane from on-ramps in areas near freeway interchanges, potentially via BSMs.	5.4.1.5; 5.4.2.2
3.3.5 The IOO roadside equipment may receive information about a string of IFM vehicles approaching a merge point and make adjustments to ramp metering in order to minimize disruptions to the IFM string.	5.4.3.1

4. 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.
CC	Cruise Control – A longitudinal control system that operates solely based on maintaining a driver set speed.
IFM	Improve Freeway Mobility – An SAE Level 1 or Level 2 Automation system using Cooperative Automation 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.
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 Road 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	Road 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.
String	One or more ACC, CACC, or IFM vehicles in succession that are formed "ad-hoc". In a string, each vehicle exercises independent control over its longitudinal behavior. Whereas, in a platoon, a leader-follower relationship is created and the vehicles implement the longitudinal control behavior determined by the leader.

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 Road 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.