Concept Development and Needs Identification for Intelligent Network Flow Optimization (INFLO)

Test Readiness Assessment

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16. Abstract

The purpose of this project is to develop for the Intelligent Network Flow Optimization (INFLO), which is one collection (or bundle) of high-priority transformative applications identified by the United States Department of Transportation (USDOT) Mobility Program for development in 2011, the following:

- Concept of Operations (ConOps)
- Functional requirements and corresponding performance requirements
- High-level data and communication needs
- Test readiness Assessment Document

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1 Introduction

1.1 Background

In support of USDOT's Intelligent Transportation Systems' (ITS) Mobility Program, several of the Department's agencies are fully engaged in exploiting active interaction between fixed and mobile transportation system entities both in the way new forms of data are being exchanged and in the opportunities that are afforded to extend the geographic scope, precision and control of our Nation's surface transportation system. An important initiative within the framework of this strategic effort is the Dynamic Mobility Applications (DMA) program which, in part, seeks to create applications that fully leverage frequently collected and rapidly disseminated multi-source data gathered from connected travelers, vehicles and infrastructure, and that increase efficiency and improve individual mobility while reducing negative environmental impacts and safety risks.

The purpose of the INFLO project is to facilitate concept development and needs refinement for the INFLO applications and to assess their readiness for development and testing. The three applications under the INFLO bundle will ultimately help to maximize roadway system productivity, enhance roadway safety and capacity, and reduce overall fuel consumption. These three applications are:

- Queue Warning (Q-WARN);
- Dynamic Speed Harmonization (SPD-HARM); and
- Cooperative Adaptive Cruise Control (CACC).

1.2 Document Overview

The USDOT initiated this Systems Engineering (SE) project to define the Concept of Operations (ConOps), requirements and readiness of the INFLO bundle. The ConOps is a prerequisite to this document and is recommended reading prior to reading this document. The ConOps describes the characteristics of the three applications within the IDTO bundle from the system user's viewpoints. The requirements build upon those concepts, particularly the User Needs, to document the required functionality, performance, interfaces, and other required characteristics for the INFLO applications. Both the INFLO Requirements and the Concept of Operations were used to identify and assess key technical and non-technical issues related to field-testing the INFLO bundle or its individual component applications.

The purpose of this report is to summarize the key technical and non-technical issues related to field-testing the INFLO bundle of applications. In addition, the assessment identifies the core functions of the critical INFLO systems, provides recommendations to address identified issues related to those systems, and provides an assessment of their test readiness for the 2012-2013 timeframe.

2 INFLO Test Readiness Assessment

In the following sections, the technical and non-technical issues related to the near-term deployment of the three INFLO applications will be discussed in detail. The key near-term systems and the core functions performed by these systems are identified and an assessment of their readiness for field testing is provided.

2.1 SPD-HARM

The following discussion of SPD-HARM in the near-term reflects the baseline level of performance of the SPD-HARM system as described in the near-term operational concept—see Operational Scenarios 1 and 3 (Section 6.1.1 and 6.1.3) of the INFLO Concept of Operations (ConOps). The near-term operational concept envisions the optimization of vehicle speeds in response to weather, congestion, and incidents along known fixed-point bottleneck locations (e.g., bridges, tunnels, on- and off-ramps, and positive grades). Essential connected vehicle-generated data elements include the current location, speed, acceleration/deceleration, and lane information of the vehicle. Other crucial data—including weather, road surface conditions, and facility-wide traffic conditions—will be supplemented by roadside sensors and third party sources. System-generated speed and lane usage recommendations will be disseminated to vehicles via infrastructure-to-vehicle (I2V) communication as well as traditional dynamic message signs (DMS).

2.1.1 Technical and Non-Technical Readiness of SPD-HARM Systems

The diagram below provides an overview of the SPD-HARM related systems and subsystems and how information flows between them. The numbered systems are those key systems that have the most significant impact on the test readiness of SPD-HARM in the near term. They are assessed in detail below.

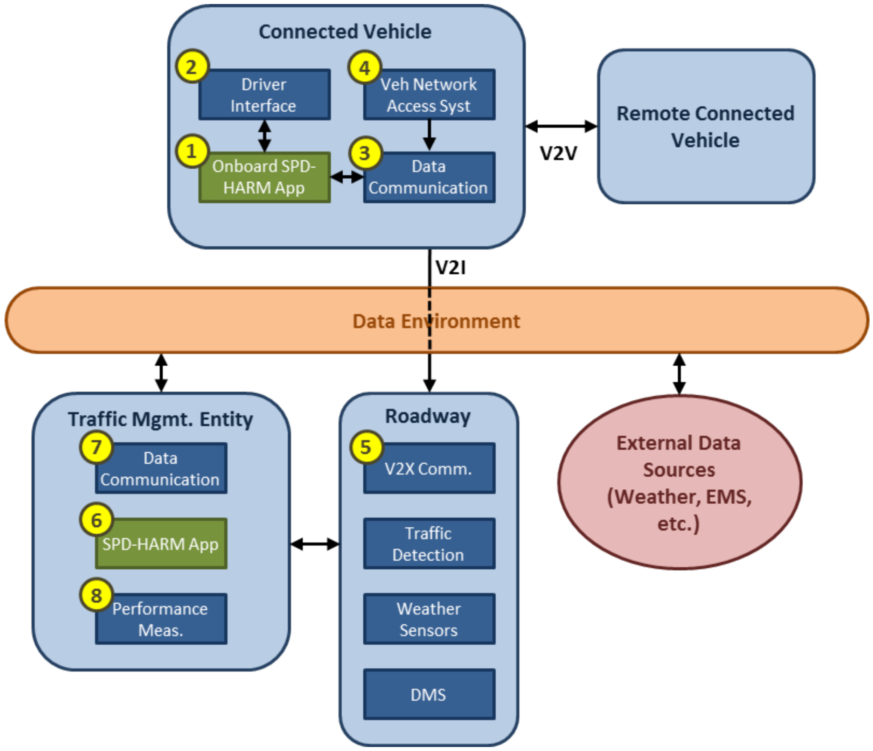

Figure 2-1. SPD-HARM Systems Information Flow Diagram

1. Connected Vehicle-based SPD-HARM Application

Essential Function: Process real-time data and generate/receive speed harmonization recommendations for the vehicle

Assessment: Test ready

Discussion: Near-term SPD-HARM deployments will likely exclusively utilize externally-generated (i.e., not vehicle-based) target speed recommendations. Therefore, the vehicle-based SPD-HARM application will be limited to receiving externally-generated target speeds, passing speed recommendations to the driver, and generating speed harmonization-related status messages to other vehicles and systems.

Further research is recommended into methods for accommodating communication latency, communication loss, and discrepancies across different data sources.

2. In-Vehicle Driver Interface

Essential Function: Display system output (e.g., target speed) and receive user input

Assessment: Test ready

Discussion: The requirements of the driver interface system have been largely met already by the systems deployed as part of the Connected Vehicle Safety Pilot project. These systems should be adapted to communicate target speed recommendations to the driver, whether via an integrated human-machine interface system or a carry-in or nomadic device.

It is recommended that additional development be done on driver interface systems that can safely present additional information that may be useful to the driver, including target lane recommendations and speed change justification information (e.g., “slowdown due to accident 1mi ahead”).

3. Connected Vehicle V2X Communication System

Essential Function: Communicate wirelessly with infrastructure and other Connected Vehicles to send and receive data and instructions

Assessment: Test ready

Discussion: The requirements of the driver interface system have been largely met already by the systems deployed as part of the Connected Vehicle Safety Pilot project. These systems should be adapted to communicate SPD-HARM specific data, including target speed recommendations and vehicle-generated/collected data, including current speed and location.

It is recommended that additional testing be done to the communications system on accommodating the dissemination of additional vehicle-collected data elements that may be useful to SPD-HARM, including brake and anti-lock brake status, impact sensor status, external temperature, wiper status, traction control status, stability control status, and differential wheel speed.

4. On-board Integrated Vehicle Network Access System

Essential Function: Read real-time vehicle data (speed, heading, temperature, etc.) to make available to the SPD-HARM Application

Assessment: Test ready

Discussion: While OBD readers are currently in wide use—in particular in the Connected Vehicle Safety Pilot Demonstration Project—the cost of installing all the required vehicle movement sensors, road surface sensors, and weather sensors as required by the SPD-HARM application may be considerable.

Collaboration with and among auto manufacturers may be required in the mid and long term in order to reduce unit costs.

5. Roadside V2I/I2V Communications System

Essential Function: Receive and send information between SPD-HARM-enabled Connected Vehicles and the TME

Assessment: Test ready

Discussion: The equipment required by the V2I/I2V roadside communications system (e.g., DSRC, cellular, WiFi) will depend on the communications requirements and protocols established by the specific SPD-HARM implementation. However, because operational testing and demonstration of these technologies is currently being done by various Connected Vehicle test beds, they are therefore considered test ready for SPD-HARM.

Installation of V2I/I2V communications equipment may require land acquisition, certain certificates, and expert workers. It is recommended that this process be facilitated through a third-party contractor. However, cost-benefit analysis is required before the outsourcing any given task.

6. Traffic Management Entity (TME)-Based SPD-HARM Application

Essential Function: Process real-time and historical transportation network data to generate segment-specific target speeds to maximize network efficiency

Assessment: Test ready, but some additional research recommended

Discussion: Speed harmonization algorithms of varying levels of complexity have been in operational deployment for some time, both nationally and internationally. These algorithms, available in the transportation literature, can be adapted for SPD-HARM. However, further research into the development of segment-specific target speed generation algorithms is recommended. In particular, algorithms should be tested and evaluated that:

- utilize online and offline modeling to determine the timing, location, and values of target speeds;
- integrate shockwave detection and prediction capabilities (in terms of start time, duration, lane location, and physical length of shockwaves); and
- integrate anticipated levels of driver compliance for given target speeds when evaluating speed harmonization strategies.

In addition to improving the target speed generating algorithms, it will be important to provide user education to improve the compliance with the target speed recommendations. The System Developer should devise effective ways to provide user education during the long-term implementation of the system.

Finally, key business relationship with third party entities should be considered and explored to acquire the required data (e.g., ITS data). The System Developer should reduce the cost of data acquisition by exploring any possible benefits that these third party entities might derive by sharing their data with the SPD-HARM application.

7. TME-Based Communications Subsystem

Essential Function: Receive multisource real-time and historical data from infrastructure-based systems and connected vehicles and send generated target speeds and relevant speed harmonization information to connected vehicles and infrastructure

Assessment: Test ready

Discussion: It is recommended that all data preparation and transfer be done utilizing a single data format (e.g., XML) in order to facilitate the data acquisition and dissemination process. It is further recommended that the System Developer select the appropriate data format (considering the size of the data) and design the system to work with this data format.

Ensuring that appropriate privacy controls are in place to protect personally identifiable information (PII) is a great concern for the SPD-HARM communications subsystem. An important ways to ensure PII protection is for the SPD-HARM system to comply with and utilize the results from the Connected Vehicle Core System Initiative, which specifies the network and data distribution services to enable DMA applications such as INFLO to send and receive data securely. Key requirements specified by the Core System Concept that are relevant to INFLO are in the areas of data distribution, network services, and user permissions.

An additional means to protect PII is to collect and retain only the minimum amount of data necessary to support the operational needs of the application. In the case of SPD-HARM—and specifically the dissemination of TME-generated target speed recommendations to enabled vehicles—very little PII would be required to be exchanged. Because TME-generated target speed recommendations are recommendations for whole segments of the road (and not for individual vehicles), the only PII that may need to be exchanged between vehicles and the infrastructure are the encrypted credentialing certificates authenticating the vehicle as a trusted user of the Connected Vehicle/INFLO network.

Likewise, data collected from the vehicle and shared with the TME (location, speed, heading) should not require any associated PII to be maintained along with that data set. Vehicle data that was anonymized would be sufficient for any SPD-HARM related analysis, target speed generation, or performance monitoring applications.

8. TME-Based Performance Monitoring Subsystem

Essential Function: Monitor the effectiveness of speed harmonization recommendations and policies on the transportation network using safety and mobility measures; provide feedback to the SPD-HARM application necessary to adjust and improve speed harmonization algorithms

Assessment: Test ready, but some additional research recommended

Discussion: Existing simulation tools should be used to conduct segment specific and network-wide performance analysis, based on travel time reliability, travel delay, shockwave misidentification, and capacity drop performance measures.

Additional research is recommended into defining methods for integrating learning into the SPD-HARM algorithms for automatic recalibration based on actual versus predicted performance outcomes.

Additional research is also recommended into how best to utilize the data environment to exchange relevant information with other dynamic mobility applications.

2.1.2 Additional Near-Term Technical and Non-Technical Issues

The following are additional key issues that may impact near-term SPD-HARM deployments and should be investigated further.

Electromagnetic interference and electromagnetic compatibility
Electromagnetic interference (EMI) is a concern for all Connected Vehicle systems, including SPD-HARM and INFLO. Because the reliability and consistency of V2V and V2I communication is important to the operation of SPD-HARM, approaches to reducing or mitigating potential communication disturbances or data degradation must be investigated.

Data processing capabilities
The incorporation of connected vehicle data, predictive algorithms, and simulation and optimization procedures in the conceptual SPD-HARM system will impose significant demands on data storage capabilities. It is likely that data storage, access, and processing technologies will require significant development in order to achieve the operational targets defined by the SPD-HARM concept. However, developments in other areas with high transaction volumes and active customer relation management in retail, financial services and electronic logistics marketplaces point to successful implementations and robust hardware and software solutions that may be readily adapted to this environment.

Preparing TMCs for new role in the Connected Vehicle environment
Multisource data collection and aggregation, strategy generation, and response dissemination are the key areas in which TMCs will play a role in the Connected Vehicle environment, and the SPD-HARM

application in particular. They are also the areas in which current TMC practices will have to evolve most significantly. Because the adoption and integration of Connected Vehicles will likely be gradual and uneven, TMCs, especially in the near-term, will have to support both legacy systems (for non-enabled vehicles) and connected vehicle-enabled systems. Many barriers will likely have to be overcome, particularly in the areas of training, funding, and institutional issues.

Drivers' willingness to follow speed recommendations
In order for the SPD-HARM concept to be successful, driver compliance with the application's speed recommendations is crucial. Absent CACC (or a similar autonomous car following environment), connected vehicle drivers will have to acknowledge and make manual throttle adjustments in response to the varying speed target recommendations of the SPD-HARM application. The effectiveness of SPD-HARM is limited by the degree to which drivers follow its recommendations. Recommendations that do not seem warranted based on traffic conditions or recommendations that come too frequently or that require severe speed adjustments risk causing drivers to stop attending to SPD-HARM recommendations completely.

Co-deployment with other mobility and safety applications
Co-deploying SPD-HARM with other applications that utilize similar data sets and processing methods could potentially reduce implementation and operational costs. Since there are complementary factors among the various mobility and safety applications, it is expected that SPD-HARM would benefit from its integration with other applications by taking advantage of the positive effects on traffic flow and safety that the other applications generate. In particular, CACC would benefit SPD-HARM by providing an automatic mechanism for harmonizing traffic flow and reducing or mitigating acceleration variability, thereby significantly increasing speed compliance and allowing for more precise management of the traffic flow.

However, application co-deployment also increases the complexity of system integration and the strain on data resources. Connected vehicle-based applications and systems are undeveloped and thus risky. Introducing applications simultaneously might multiply this risk. Speed harmonization per se could be introduced with varying degrees of sophistication starting in the early stages of connected vehicle deployment (including reactive strategies at fixed locations pre-connectivity). The sophistication could evolve as connected vehicle deployments become more mature and more prevalent, and the science base advances through application and testing.

2.1.3 SPD-HARM Near-Term Requirements Achievability

This section presents the near-term SPD-HARM requirements that were identified in Task 3 (*Functional and Performance Requirements, and High-Level Data and Communication Needs for INFLO*) and provides a summary assessment of their achievability within the next few years. Refer to the Task 3 document for additional details about the requirements presented here, including associated systems and subsystems and user needs addressed.

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RS-1.1	The Connected Vehicle-based SPD-HARM application shall pass target speed recommendations to the driver interface system.	H	Yes

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RS-1.2	The Connected Vehicle driver interface system shall communicate segment-specific target speed recommendations to the driver.	H	Yes
RS-1.2.1	The Connected Vehicle driver interface system shall communicate segment-specific target speed recommendations to the driver utilizing auditory, visual, or haptic alerts and on-screen messages.	H	Yes
RS-3.1	The Connected Vehicle-based SPD-HARM application shall pass speed change justification information to the driver interface system.	M	Maybe
RS-3.2	The Connected Vehicle driver interface system shall communicate speed change justification information to the driver.	M	Yes
RS-3.2.1	The Connected Vehicle driver interface system shall communicate speed change justification information to the driver utilizing auditory or visual (on-screen) messages.	M	Yes
RS-4.1	The Connected Vehicle-based SPD-HARM application shall utilize secure data transmission methods when disseminating any personally identifiable information.	H	Yes
RS-4.2	The Traffic Management Entity shall anonymize all personally identifiable information obtained from Connected Vehicles.	H	Yes
RS-4.3	The Traffic Management Entity shall use secure transmission methods for disseminating target speed and lane recommendations and justification for speed changes	H	Yes
RS-4.4	The Traffic Management Entity shall protect systems and data (including PII) from unauthorized access.	H	Yes
RS-5.1	The Connected Vehicle-based SPD-HARM application shall communicate with the Integrated Vehicle Network Access System to gather real-time vehicle-collected data from the vehicle network.	M	Yes
RS-5.1.1a	The Connected Vehicle-based SPD-HARM application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (time, location, velocity, heading, acceleration) from the vehicle network.	M	Yes
RS-5.2	Communications between the Connected Vehicle-based SPD-HARM application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	H	Yes
RS-6.2a	The Connected Vehicle-based SPD-HARM application shall disseminate vehicle-collected data (current speed, current location, current acceleration/deceleration) to infrastructure systems utilizing V2I communication.	M	Yes

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RS-7.2	The Connected Vehicle-based SPD-HARM application shall have the ability to receive target speed recommendations, target lane recommendations and justification for speed changes from infrastructure-based systems utilizing I2V communication.	H	Partially (target speeds - yes; lane and justification – maybe)
RS-9.1	The Traffic Management Entity (TME)-based SPD-HARM application shall have a data collection capability for receiving real-time data from multiple sources.	H	Yes
RS-9.1.1	The TME-based SPD-HARM application shall have a data collection capability for receiving real-time traffic, road conditions, and weather data from infrastructure-based systems.	H	Yes
RS-9.1.2a	The TME-based SPD-HARM application shall have the capability to receive real-time traffic (including location and speed) from connected vehicles.	H	Yes
RS-9.2	The TME-based SPD-HARM application shall have the capability to access a data environment that includes historical traffic data (including speed, flow and density), road conditions data (e.g. ice, wet, etc.), and weather data (clear, rainy and snowy).	L	Yes
RS-10.1	The TME-based SPD-HARM application shall be capable of fusing and processing data from various sources to make target speed recommendations.	H	Yes
RS-10.1.1a	The TME-based SPD-HARM application shall utilize real-time traffic data when calculating the recommended target speed.	H	Yes
RS-10.1.2	The TME-based SPD-HARM application shall utilize real-time and predicted weather data when calculating the recommended target speed.	M	Yes
RS-10.1.3	The TME-based SPD-HARM application shall utilize real-time and predicted road surface data when calculating the recommended target speed.	M	Yes
RS-10.2	The TME-based SPD-HARM application shall have a shockwave detection capability for known fixed bottleneck locations.	M	Maybe (depends on degree of investment in detection equip. and quality of developed algorithms)
RS-10.2.1	The TME-based SPD-HARM application shall have a shockwave detection capability that identifies at least 95% of all shockwave occurrences for known fixed bottleneck locations.	L	No (unlikely that detection penetration and algorithm quality will be sufficient)

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RS-10.2.2	The TME-based SPD-HARM application shall have a false positive identification rate of no more than 5% of all shockwave events at known fixed bottleneck locations.	L	No (unlikely that detection penetration and algorithm quality will be sufficient)
RS-10.2.3	The TME-based SPD-HARM application shall detect formed shockwaves within 5 seconds of formation at known fixed bottleneck locations.	L	No (unlikely that detection penetration and algorithm quality will be sufficient)
RS-10.2.4	The TME-based SPD-HARM application shall determine the lane(s) impacted by the formed shockwave.	L	Maybe
RS-10.2.4.1	The TME-based SPD-HARM application shall determine the lane(s) impacted by the formed shockwave within 5 seconds of shockwave detection.	L	No (unlikely that detection penetration and algorithm quality will be sufficient)
RS-10.2.5	The TME-based SPD-HARM application shall determine the length of the formed shockwave.	L	Maybe
RS-10.2.5.1	The TME-based SPD-HARM application shall determine the length of the formed shockwave to within 10 ft.	L	No (unlikely that detection penetration and algorithm quality will be sufficient)
RS-10.2.5.2	The TME-based SPD-HARM application shall determine the length of the formed shockwave within 5 seconds of shockwave detection.	L	No (unlikely that detection penetration and algorithm quality will be sufficient)
RS-10.2.5.3	The TME-based SPD-HARM application shall update the current shockwave length estimation once per second.	L	No (unlikely that detection penetration and algorithm quality will be sufficient)
RS-10.2.6a	The TME-based SPD-HARM application shall utilize real-time traffic data in shockwave detection algorithms.	L	Yes
RS-10.2.6b	The TME-based SPD-HARM application shall utilize road condition and weather data in shockwave detection algorithms.	L	Yes
RS-11.1	The TME-based SPD-HARM application shall have a target speed generation capability.	H	Yes
RS-11.1.1	The TME-based SPD-HARM application shall generate target speed strategies for different segments of the roadway.	H	Yes

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RS-11.1.2a	The TME-based SPD-HARM application shall generate target speed strategies that consider downstream traffic conditions, weather, and local roadway surface conditions.	H	Yes
RS-12.1	The TME-based SPD-HARM application shall have a target speed recommendation dissemination capability.	H	Yes
RS-12.1.1	The TME-based SPD-HARM application shall disseminate target speed recommendations to SPD-HARM enabled connected vehicles on the facility via I2V communications.	H	Yes
RS-12.1.2	The TME-based SPD-HARM application shall disseminate target speed recommendations to DMS locations.	H	Yes
RS-13.1	The TME-based Performance Monitoring Subsystem shall have the capability to conduct segment-specific and network-wide operational performance analysis.	H	Yes
RS-13.1.1	The TME-based SPD-HARM application shall conduct operational performance analysis in terms of travel time reliability, travel delay, and capacity drop.	H	Maybe
RS-13.1.2	The TME-based Performance Monitoring Subsystem shall conduct operational performance analysis utilizing meso- and micro-simulation.	H	Yes
RS-13.2	The TME-based Performance Monitoring Subsystem shall generate trends and historical performance reports.	H	Yes
RS-13.3	The TME-based Performance Monitoring Subsystem shall have the capability to assess the reliability of data.	H	Maybe
RS-13.4	The TME-based SPD-HARM application shall be modifiable such that algorithms and software performance can be improved.	H	Maybe
RS-13.5	The TME-based Performance Monitoring Subsystem shall continuously compare the actual performance of the system with the performance determined by the SPD-HARM application to determine recommended calibrations to the application.	H	Maybe
RS-14.1	The SPD-HARM application shall make SPD-HARM-derived target speed information (impacted road segments, target speeds recommended, user messages provided) available for sharing with other dynamic mobility applications.	L	Maybe (depends on implementation sequencing and coordination)
RS-14.2	The SPD-HARM application shall make SPD-HARM-derived shockwave/breakdown formation information ([predicted] time of formation, length, duration, lanes impacted, user messages provided) available for sharing with other dynamic mobility applications.	L	Maybe (depends on implementation sequencing and coordination)

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RS-14.3	SPD-HARM-derived target speed information and shockwave/breakdown formation information shall be shared with other DMAs via the Traffic Management Entity and/or the Data Environment.	L	Maybe (depends on implementation sequencing and coordination)

2.2 Q-WARN

The following discussion of Q-WARN in the near-term reflects the baseline level of performance of the Q-WARN system as described in the near-term operational concept—see Q-WARN Operational Scenarios 1 and 3 (Section 6.2.1 and 6.2.3) of the INFLO Concept of Operations (ConOps). The near-term operational concept envisions the generation of queue warnings along known fixed-point queue generation locations (e.g., exit ramps, border crossings, lane merges, bridges, and tunnels) using a combination of V2I-based in-vehicle alerts and traditional infrastructure message signs. Essential connected vehicle-generated data elements include the current location, speed, acceleration/deceleration, and lane information of the vehicle. Other crucial data—including weather, road surface conditions, and facility-wide traffic conditions—will be supplemented by roadside sensors and third party sources.

2.2.1 Technical and Non-Technical Readiness of Q-WARN Systems

The diagram below provides an overview of the Q-WARN related systems and subsystems and how information flows between them. The numbered systems are those key systems that have the most significant impact on the test readiness of Q-WARN in the near term. They are assessed in detail below.

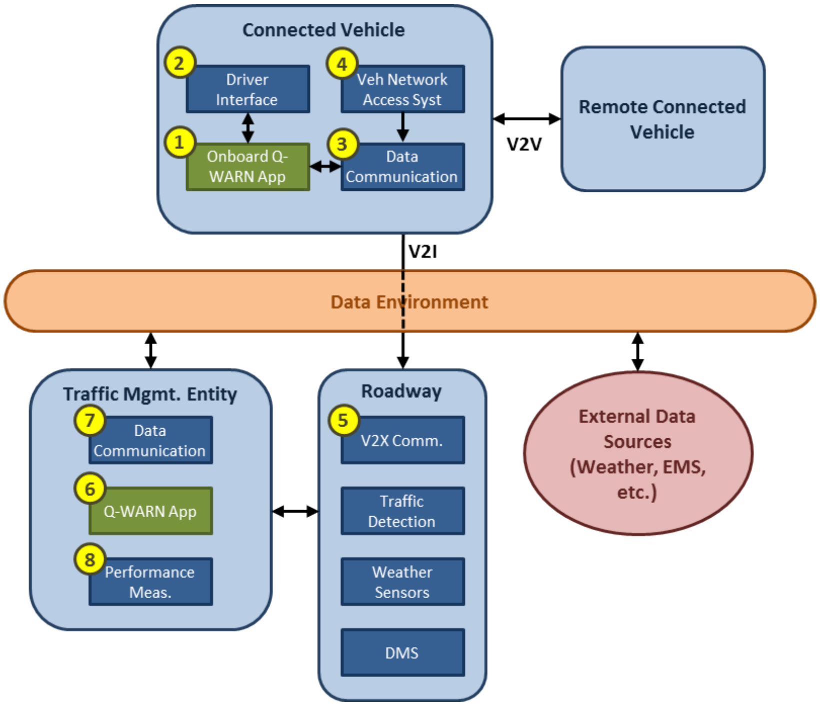

Figure 2-2. Q-WARN Systems Information Flow Diagram

1. Connected Vehicle-based Q-WARN Application

Essential Function: Process real-time data, generate/receive queue warnings, and self-detect queued states

Assessment: Partially test ready, but more research recommended for vehicle-based queue detection

Discussion: Near-term Q-WARN deployments will likely exclusively utilize externally-generated (i.e., not vehicle-based) queue warnings due to low anticipated penetration levels of enabled vehicles. However, real-time queue detection will be at least partially derived from individual vehicle self-detection of queued states. Therefore, vehicle-based queue detection algorithms will have to be developed that reliably and quickly determine queued states based on available vehicle sensor information and any available V2V location and deceleration information from surrounding vehicles. Research in this area is limited and so significant algorithm development and testing may be necessary if vehicle-based queue determination is to be used in near-term deployment.

Further research is recommended into methods for accommodating communication latency, communication loss, and discrepancies across different data sources.

2. In-Vehicle Driver Interface

Essential Function: Display system output (e.g., individualized queue warning) and receive user input

Assessment: Partially test ready, but more research recommended on appropriate methods for communicating individualized (i.e., vehicle location-specific) queue warnings

Discussion: The requirements of the driver interface system have been largely met already by the systems deployed as part of the Connected Vehicle Safety Pilot project. These systems should be adapted to communicate individualized queue warnings to the driver, whether via an integrated human-machine interface system or a carry-in or nomadic device.

However, it is recommended that additional research and development be done on driver alert generation algorithms. In particular, the algorithm should be able to provide useful and appropriate individualized queue warnings and related messages that take into account the severity of the queue condition and the individual vehicle's location relative to the queue endpoint and estimated time to intercept. Testing will be needed to ensure that the information presented is useful and conveyed in a manner that does not present significant driver distraction-related safety issues.

3. Connected Vehicle V2X Communication System

Essential Function: Communicate wirelessly with infrastructure and other Connected Vehicles to send and receive data and instructions

Assessment: Test ready

Discussion: The requirements of the driver interface system have been largely met already by the systems deployed as part of the Connected Vehicle Safety Pilot project. These systems should be adapted to communicate Q-WARN specific data, including location and characteristics of identified queues.

It is recommended that additional testing be done on the ability of the communications system to accommodate the dissemination of additional vehicle-collected data elements that may be useful to Q-WARN, including brake status and impact sensor status, vehicle gap information, and vehicle-generated queued state determinations.

4. On-board Integrated Vehicle Network Access System

Essential Function: Read real-time vehicle data (speed, heading, lane location, etc.) to make available to the Q-WARN Application

Assessment: Test ready

Discussion: While OBD readers are currently in wide use—in particular in the Connected Vehicle Safety Pilot Demonstration Project—the cost of installing all the required vehicle movement sensors as required by the Q-WARN application may be considerable. Collaboration with and among auto manufacturers may be required in the mid- and long-term in order to reduce the unit cost.

5. Roadside V2I/I2V Communications System

Essential Function: Receive and send information between Q-WARN-enabled Connected Vehicles and the TME

Assessment: Test ready

Discussion: The equipment required by the V2I/I2V roadside communications system (e.g., DSRC, cellular, WiFi) will depend on the communications requirements and protocols established by the specific Q-WARN implementation. However, because various Connected Vehicle test beds are currently doing operational testing and demonstration of these technologies, they are therefore considered test ready for Q-WARN.

Installation of V2I/I2V communications equipment may require land acquisition, certain certificates, and expert workers. It is recommended that this process be facilitated through a third-party contractor. However, cost-benefit analysis is required before outsourcing any given task.

6. Traffic Management Entity (TME)-Based Q-WARN Application

Essential Function: Process real-time and historical transportation network data to identify formed queues and generate queue warnings to appropriate upstream locations

Assessment: Partially test ready, but additional research into queue characteristics determination is recommended

Discussion: Queue warning algorithms of varying levels of complexity have been in operational deployment for some time, both nationally and internationally. These algorithms, available in the transportation literature, can be adapted for the near-term Q-WARN system, especially if it is deployed at a known fixed-point queue generation location. However, further research into queue characteristics determination algorithms is recommended. In particular, the such algorithms should be able to determine reliably:

- lane(s) impacted by the queue;
- number of vehicles in the queue;
- endpoint location/length of the queue; and
- traveling speed of the queue.

In addition to improving the queue detection algorithms, it will be important to provide user education to improve driver response to queue warnings and compliance with any recommendation provided by the Q-WARN application. The System Developer should devise effective ways to provide user education during the implementation of the system.

Finally, key business relationship with third party entities should be considered and explored to acquire the required data (e.g., ITS data). The System Developer should reduce the cost of data acquisition by exploring any possible benefits that these third party entities might derive by sharing their data with the Q-WARN application.

7. TME-Based Communications Subsystem

Essential Function: Receive multisource real-time and historical data from infrastructure-based systems and connected vehicles and send queue warnings to connected vehicles and infrastructure

Assessment: Test ready

Discussion: It is recommended that all data preparation and transfer be done utilizing a single data format (e.g., XML) in order to facilitate the data acquisition and dissemination process. It is further recommended that the System Developer select the appropriate data format (considering the size of the data) and design the system to work with this data format.

As with SPD-HARM, ensuring that appropriate privacy controls are in place to protect personally identifiable information (PII) is a great concern for the Q-WARN communications subsystem. An important ways to ensure PII protection is for the Q-WARN system to comply with and utilize the results from the Connected Vehicle Core System Initiative, which specifies the network and data distribution services to enable DMA applications such as INFLO to send and receive data securely. Key requirements specified by the Core System Concept that are relevant to INFLO are in the areas of data distribution, network services, and user permissions.

An additional means to protect PII is to collect and retain only the minimum amount of data necessary to support the operational needs of the application. In the case of Q-WARN—and specifically the dissemination of TME-generated queue warnings to enabled vehicles—very little PII would be required to be exchanged. TME-generated queue warnings are generic warnings for particular road segments and provide information about the location and length of the queue. Enabled vehicles in the vicinity that receive these recommendations use the queue information provided and, combined with their awareness of their location with respect to the queue end, generate individualized alerts to the drivers. Therefore, the only PII that may need to be exchanged between individual vehicles and the infrastructure are the encrypted credentialing certificates authenticating the vehicle as a trusted user of the Connected Vehicle/INFLO network.

Likewise, data collected from the vehicle and shared with the TME (location, speed, heading) should not require any associated PII to be maintained along with that data set. Vehicle data that was anonymized would be sufficient for any Q-WARN related analysis, target speed generation, or performance monitoring applications.

8. TME-Based Performance Monitoring Subsystem

Essential Function: Monitor the effectiveness of queue determinations and queue warnings on the transportation network using safety and mobility measures; provide feedback to the Q-WARN application necessary to adjust and improve queue determination and queue warning algorithms

Assessment: Test ready, but some additional research recommended

Discussion: Existing simulation tools should be used to conduct segment specific and network-wide performance analysis, based on number of secondary crashes, travel time reliability, travel delay, and shockwave misidentification performance measures.

Additional research is recommended into defining methods for integrating learning into the Q-WARN determination and alert generation algorithms for automatic recalibration based on actual versus predicted performance outcomes.

Additional research is also recommended as to how best to utilize the data environment to exchange relevant information with other dynamic mobility applications.

2.2.2 Additional Near-Term Technical and Non-Technical Issues

The following are additional key issues that may impact near-term Q-WARN deployments and should be investigated further.

Electromagnetic interference and electromagnetic compatibility
Electromagnetic interference (EMI) is a concern for all Connected Vehicle systems, including Q-WARN and INFLO. Because the reliability and consistency of V2V and V2I communication is important to the operation of Q-WARN, approaches to reducing or mitigating potential communication disturbances or data degradation must be investigated.

Data processing and storage
Data processing and storage represents a significant component of the Q-WARN system and is computationally and resource intensive. The Q-WARN operating agency can reduce this burden by outsourcing the processing and storage of data to third-parties that might be better able to accommodate the demands on the data.

One concern with the outsourcing approach is the increased exposure of data it entails. Data security and privacy issues would have to be resolved before any large scale data outsourcing program is begun.

Preparing TMCs for new role in the Connected Vehicle environment

Multisource data collection and aggregation, strategy generation, and response dissemination are the key areas in which TMCs will play a role in the Connected Vehicle environment, and the Q-WARN application in particular. They are also the areas in which current TMC practices will have to evolve most significantly. Because the adoption and integration of Connected Vehicles will likely be gradual and uneven, TMCs, especially in the near-term, will have to support both legacy systems (for non-enabled vehicles) and connected vehicle-enabled systems. Many barriers will likely have to be overcome, particularly in the areas of training, funding, and institutional issues.

Co-deployment with other mobility and safety applications

Co-deploying Q-WARN with other applications that utilize similar data sets and processing methods could potentially reduce implementation and operational costs. Since there are complementary factors among the various mobility and safety applications, it is expected that Q-WARN would benefit from its integration with other applications by taking advantage of the positive effects on traffic flow and safety that the other applications generate. In particular, SPD-HARM would benefit Q-WARN by effectively slowing and managing upstream traffic, thus reducing the risk of secondary collisions caused by sudden stopping.

However, application co-deployment also increases the complexity of system integration and the strain on data resources. Connected vehicle-based applications and systems are undeveloped and thus risky. Introducing applications simultaneously might multiply this risk.

2.2.3 Q-WARN Near-Term Requirements Achievability

This section presents the near-term Q-WARN requirements that were identified in Task 3 (*Functional and Performance Requirements, and High-Level Data and Communication Needs for INFLO*) and provides a summary assessment of their achievability within the next few years. Refer to the Task 3 document for additional details about the requirements presented here, including associated systems and subsystems and user needs addressed.

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RQ-1.1a	The Connected Vehicle-based Q-WARN application shall pass individualized queue warnings and queue characteristic information (based on vehicle's distance to end of queue) to the driver interface system.	H	Yes
RQ-1.2a	The Connected Vehicle driver interface system shall communicate queue warnings and queue characteristic information (based on vehicle's distance to end of queue) to the driver.	H	Yes
RQ-1.2.1	The Connected Vehicle driver interface system shall communicate queue warnings and queue information to the driver utilizing auditory, visual, or haptic alerts and auditory or visual (on-screen) messages.	H	Yes

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RQ-3.1	The Connected Vehicle-based Q-WARN application shall utilize secure data transmission methods when disseminating any personally identifiable information.	H	Yes
RQ-3.2	The Traffic Management Entity shall anonymize all personally identifiable information obtained from Connected Vehicles.	H	Yes
RQ-3.3	The Traffic Management Entity shall use secure transmission methods for disseminating queue warnings, queue characteristic information, and response strategies.	H	Yes
RQ-3.4	The Traffic Management Entity shall protect systems and data (including PII) from unauthorized access.	H	Yes
RQ-4.1	The Connected Vehicle-based Q-WARN application shall have the ability to detect when the vehicle is in a queued state.	M	Maybe (depends on quality of algorithm developed)
RQ-4.2	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather real-time vehicle-collected data from the vehicle network.	M	Yes
RQ-4.2.1a	The Connected Vehicle-based Q-WARN application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (time, location, velocity, heading, acceleration) from the vehicle network.	M	Yes
RQ-4.3	Communications between the Connected Vehicle-based Q-WARN application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	H	Yes
RQ-5.2	The Connected Vehicle-based Q-WARN application shall disseminate a queued status alert to infrastructure systems via V2I communication.	M	Yes (assumes near-term deployment is at a fixed queue gen location with sufficient penetration of V2I infrastructure)
RQ-6.1	The Connected Vehicle-based Q-WARN application shall have the ability to receive queue warning messages via I2V communication channels.	H	Yes (assumes near-term deployment is at a fixed queue gen location with sufficient penetration of V2I infrastructure)

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RQ-7.1	The Connected Vehicle-based Q-WARN application shall individualize generic queue warning message based on vehicle's position and distance to the end of the queue.	H	Yes
RQ-9.1.1	The Traffic Management Entity (TME)-based Q-WARN application shall have a data collection capability for receiving real-time traffic, road conditions, and weather data from infrastructure-based systems.	H	Yes
RQ-9.2	The TME-based Q-WARN application shall have the capability to access a data environment that includes historical traffic data (including speed, flow and density), road conditions data (e.g. ice, wet, etc.), and weather data (clear, rainy and snowy).	L	Yes
RQ-10.1	The Traffic Management Entity shall communicate traffic, road condition, and weather data to connected vehicles/devices via I2V communications systems.	M	Yes
RQ-11.1	The TME-based Q-WARN application shall be capable of fusing and processing data from various sources to perform queue detection.	H	Yes
RQ-11.1.1a	The TME-based Q-WARN application shall utilize real-time data in queue detection algorithms.	H	Yes
RQ-11.1.2a	The TME-based Q-WARN application shall utilize real-time weather data in queue detection algorithms.	L	Maybe
RQ-11.1.3a	The TME-based Q-WARN application shall utilize real-time road surface data in queue detection algorithms.	L	Maybe
RQ-11.2	The TME-based Q-WARN application shall have a queue detection capability for known fixed queue generation locations.	H	Yes
RQ-11.3	The TME-based Q-WARN application shall determine the lane(s) impacted by the formed queue.	M	Yes (assumes deployment is at a fixed queue gen location with sufficient penetration of detection equip.)
RQ-11.4	The TME-based Q-WARN application shall determine the length of the formed queue.	M	Maybe
RQ-11.5	The TME-based Q-WARN application shall determine the number of vehicles in the formed queue.	M	Maybe
RQ-11.6	The TME-based Q-WARN application shall determine the traveling speed and direction of the formed queue.	M	Maybe

ID	Near-Term Requirement	Priority (H/M/L)	Achievable in Near-Term?
RQ-13.3	The Traffic Management Entity shall provide user education on the need to comply with queue warning response recommendations.	M	Yes
RQ-14.1	The TME-based Q-WARN application shall have a queue warning and queue information dissemination capability.	H	Yes
RQ-14.1.1	The TME-based Q-WARN application shall disseminate queue warnings and queue information to DMS locations.	H	Yes
RQ-14.1.2	The TME-based Q-WARN application shall disseminate queue warnings and queue information to connected vehicles.	H	Yes
RQ-14.1.3	The TME-based Q-WARN application shall disseminate queue warnings and queue information to traveler information systems (e.g., 511).	L	Yes
RQ-15.1	The TME-based Performance Monitoring Subsystem shall have the capability to conduct segment-specific and network-wide operational performance analysis.	H	Yes
RQ-15.2	The TME-based Q-WARN application shall provide a means to identify, track, and analyze unidentified or mis-identified queue formation events.	H	Maybe
RQ-15.4	The TME-based Performance Monitoring Subsystem shall generate trends and historical performance reports.	H	Yes
RQ-15.5	The TME-based Performance Monitoring Subsystem shall have the capability to assess the reliability of data.	H	Maybe
RQ-15.6	The TME-based Q-WARN application shall be modifiable such that algorithms and software performance can be improved.	H	Maybe

2.3 CACC

The following discussion of CACC in the near-term reflects the baseline level of performance of the CACC system as described in the near-term operational concept—see CACC Operational Scenario discussion (Section 6.4) in the INFLO Concept of Operations (ConOps). The near-term operational concept envisions an integrated corridor that utilizes dedicated CACC managed lanes, in which CACC-enabled vehicles form and travel in ad-hoc platoons. Drivers establish their own following gaps, which are automatically maintained between vehicles utilizing V2V DSRC communications supplemented by traditional adaptive cruise control vehicle sensor systems (e.g., radar, cameras). While in the CACC managed lanes, longitudinal control is maintained autonomously by the vehicle but latitudinal control is always under the control of the driver.

2.3.1 Technical and Non-Technical Readiness of CACC Systems

The diagram below provides an overview of the CACC related systems and subsystems and how information flows between them. The numbered systems are those key systems that have the most significant impact on the test readiness of CACC in the near term. They are assessed in detail below.

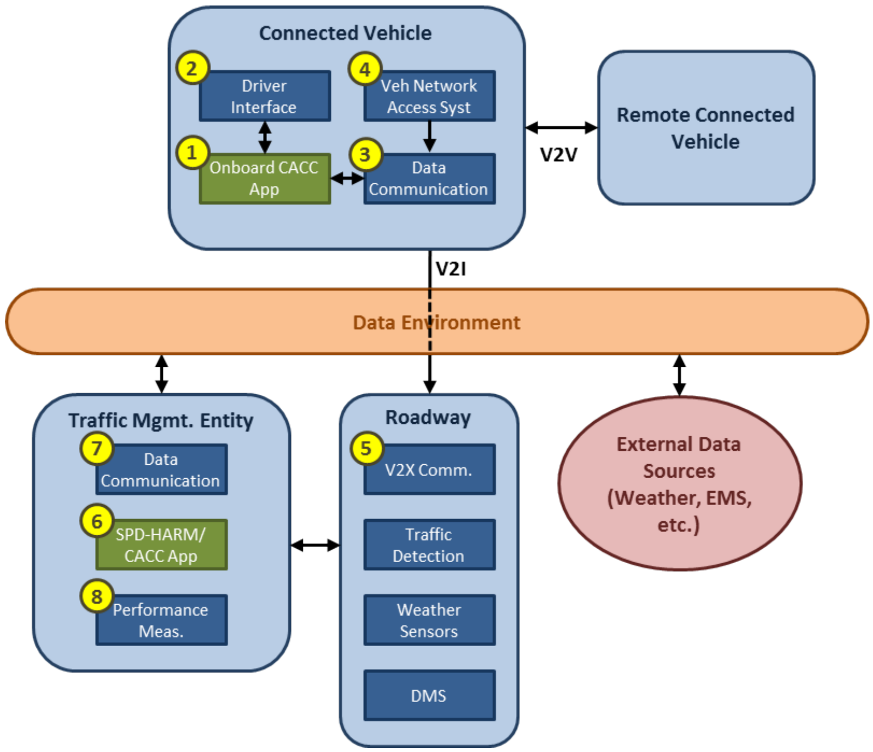

Figure 2-3. CACC Systems Information Flow Diagram

1. Connected Vehicle-based CACC Application

Essential Function: Process real-time data and make individual vehicle gap, speed, and other CACC decisions

Assessment: Partially test ready, but additional research recommended

Discussion: Near-term CACC deployments are envisioned to take the form of dedicated CACC managed lanes, in which CACC-enabled vehicles form and travel in ad-hoc platoons and drivers establish their own following gaps.

Traditional adaptive cruise control (ACC)-based sensor information will supplement V2V data to establish and maintain prescribed speed and gap policies.

Further research is recommended in the following areas:

- Reliably merging ACC-based sensor information with V2V data to generate an accurate representation of the relative positions and speeds between vehicles.
- Merging TME-based speed targets (e.g., for the purposes of speed harmonization in response to downstream congestion) with vehicle-implemented speed and gap policies.
- Methods for accommodating communication latency, communication loss, and discrepancies across different data sources.

Lastly, the long-term CACC concept envisions platoons that are not merely ad-hoc, but are formed based on specific vehicle performance characteristics (e.g., heavy duty truck-specific platoons). This, however, will require that vehicles be able to identify and locate other connected vehicles in a platoon. Currently, Connected Vehicle standards do not support the use of the technology to target individual vehicles. However, in order to achieve the transformative benefits envisioned by the long-term CACC concept, algorithms must be developed and standards established to support targeted vehicle identification, locating, and data exchange.

2. In-Vehicle Driver Interface

Essential Function: Display system output (e.g., current speed and forward gap) and receive user input (e.g., new speed and gap policy)

Assessment: Test ready

Discussion: Adaptive cruise control driver interface systems have been deployed commercially for some time and are well established. The near-term CACC driver interface system is envisioned to be very similar to such existing systems. However, it is recommended that additional development be done on ways to integrate display of TME-based speed harmonization target speeds with CACC speed and gap policy display.

3. Connected Vehicle V2X Communication System

Essential Function: Communicate wirelessly with infrastructure and other Connected Vehicles to send and receive data and instructions

Assessment: Test ready

Discussion: The requirements of the driver interface system have been largely met already by the V2V systems deployed as part of the Connected Vehicle Safety Pilot project. These systems should be adapted to communicate CACC specific data, including speed and gap data.

4. On-board Integrated Vehicle Network Access System

Essential Function: Read real-time vehicle data (speed, heading, temperature, etc.) and ACC sensor data (e.g., forward gap) to make available to the CACC Application

Assessment: Test ready

Discussion: While OBD readers are currently in wide use—in particular in the Connected Vehicle Safety Pilot Demonstration Project—the cost of installing all the required vehicle movement sensors, road surface sensors, and weather sensors as required by the CACC application in order to ensure safe following speeds and gaps may be considerable. Collaboration with and among auto manufacturers may be required in the mid- and long-term in order to reduce the unit price.

5. Roadside V2I/I2V Communications System

Essential Function: Receive and send information between CACC-enabled Connected Vehicles and the TME

Assessment: Test ready

Discussion: The equipment required by the V2I/I2V roadside communications system (e.g., DSRC, cellular, WiFi) will depend on the communications requirements and protocols established by the specific CACC implementation. However, because various Connected Vehicle test beds are currently doing operational testing and demonstration of these technologies, they are therefore considered test ready for CACC.

Installation of V2I/I2V communications equipment may require land acquisition, certain certificates, and expert workers. It is recommended that this process be facilitated through a third-party contractor. However, cost-benefit analysis is required before outsourcing any given task.

6. Traffic Management Entity (TME)-Based SPD-HARM Application

Essential Function: Process real-time and historical transportation network data to generate segment-specific target speeds for platooning CACC vehicles to maximize network efficiency

Assessment: Test ready, but some additional research recommended

Discussion: Speed harmonization algorithms of varying levels of complexity have been in operational deployment for some time, both nationally and internationally. These algorithms, available in the transportation literature, can be adapted to provide target speeds to CACC vehicles. However, further research into the development of segment-specific target speed generation algorithms is recommended. In particular, algorithms should be tested and evaluated that:

- utilize online and offline modeling to determine the timing, location, and values of target speeds; and
- integrate shockwave detection and prediction capabilities (in terms of start time, duration, lane location, and physical length of shockwaves).

Finally, key business relationship with third party entities should be considered and explored to acquire the required data (e.g., ITS data). The System Developer should reduce the cost of data acquisition by exploring any possible benefits that these third party entities might derive by sharing their data with the SPD-HARM and CACC applications.

7. TME-Based Communications Subsystem

Essential Function: Receive multisource real-time and historical data from infrastructure-based systems and connected vehicles and send generated target speeds and relevant speed harmonization information to connected vehicles and infrastructure

Assessment: Test ready

Discussion: It is recommended that all data preparation and transfer be done utilizing a single data format (e.g., XML) in order to facilitate the data acquisition and dissemination process. It is further recommended that the System Developer select the appropriate data format (considering the size of the data) and design the system to work with this data format.

8. TME-Based Performance Monitoring Subsystem

Essential Function: Monitor the effectiveness of speed harmonization recommendations and policies on the CACC managed lanes using safety and mobility measures; provide feedback to the CACC-optimized SPD-HARM application necessary to adjust and improve speed harmonization algorithms

Assessment: Test ready, but some additional research recommended

Discussion: Existing simulation tools should be used to conduct segment specific and network-wide performance analysis, based on travel time reliability, travel delay, shockwave misidentification, and capacity drop performance measures.

Research is recommended into optimizing target speed algorithms that make use of the unique benefits that semi-autonomous platooning vehicles (i.e., those vehicles traveling in the CACC managed lanes) offer. In particular, their ability to:

- Automatically and immediately implement target speeds
- Achieve precise target speeds and be capable of adjusting speeds as frequently as needed (beyond what could be expected of vehicles utilizing manual longitudinal control)

Additional research is recommended into defining methods for integrating learning into the CACC-optimized SPD-HARM algorithms for automatic recalibration based on actual versus predicted performance outcomes.

Additional research is also recommended as to how best to utilize the data environment to exchange relevant information with other dynamic mobility applications.

2.3.2 Additional Near-Term Technical and Non-Technical Issues

Due to the fact that CACC, unlike SPD-HARM and Q-WARN, utilizes semi-autonomous vehicle control and relies so significantly on stable, dependable V2V communication, potential CACC issues deserve additional scrutiny. Several of the key technical and non-technical issues relevant to CACC are highlighted below.

Electromagnetic interference and electromagnetic compatibility
Electromagnetic interference (EMI) is a concern for all Connected Vehicle systems, including CACC and INFLO. Because the reliability and consistency of V2V and V2I communication is important to the operation of CACC, approaches to reducing or mitigating potential communication disturbances or data degradation must be investigated.

Brake and throttle actuation
CACC requires that the vehicle systems be automatically actuated to achieve the longitudinal performance needed. This hardware (or software in the case of drive-by-wire) is typically not included in today's vehicles and as such must be integrated with CACC systems.

Digital map availability
A digital map of high resolution would provide a means for CACC and all INFLO-enabled vehicles to perform lane identification and to operate more efficiently, by recognizing changes in the roadway horizontal and vertical profiles to adjust speed as necessary. Furthermore, high resolution maps can also provide the system with information on location of various traffic control devices including stop and traffic signalized intersections.

Vehicle location solutions

Accurate vehicle locating is an important component of CACC as well as the other INFLO applications. One approach to providing enhanced vehicle locating is the use of Wide Area Augmented System (WAAS) Global Positioning Systems (GPS), which utilizes ground-based reference stations to supplement GPS signals. Dead reckoning is another approach that may be part of the vehicle locating solution to provide back-up vehicle tracking in the event that the GPS signal is lost. Vehicle-mounted sensor systems and infrastructure-based detection may also play a role in Connected Vehicle locating and positioning. These and other solutions should be examined during detailed design and testing phases of the mobility applications programs.

Achieving necessary market penetration rates
Given that high levels of market penetration are likely to be needed for the system to operate successfully, how can the initial deployment ensure adequate participation levels? Are there ways ? What applications should be introduced first that would not necessarily require high levels of market penetration to be successful?

Identifying a suitable pilot site
A near-term CACC deployment would work best in a dedicated managed lane. However, it would likely be a significant challenge to identify existing infrastructure to repurpose into a CACC-only lane that would be supported by local stakeholders or to construct a new facility for such a purpose. Consideration therefore may have to be given to alternate approaches in which CACC vehicles share a facility with non-enabled vehicles (e.g., HOV lanes).

Liability issues
What are the litigation issues that have to be dealt with in the event of an accident involving CACC systems? Vehicle manufacturers in particular are concerned about the risks and liability potential associated with vehicle systems that rely on externally generated information.

Preparing TMCs for new role in the Connected Vehicle environment
Multisource data collection and aggregation, strategy generation, and response dissemination are the key areas in which TMCs will play a role in the Connected Vehicle environment, especially if CACC is deployed with a speed harmonization component. They are also the areas in which current TMC practices will have to evolve most significantly. Because the adoption and integration of Connected Vehicles will likely be gradual and uneven, TMCs, especially in the near-term, will have to support both legacy systems (for non-enabled vehicles) and connected vehicle-enabled systems. Many barriers will likely have to be overcome, particularly in the areas of training, funding, and institutional issues.

Co-deployment with other mobility and safety applications
Co-deploying CACC with other applications that utilize similar data sets and processing methods could potentially reduce implementation and operational costs. Since there are complementary factors among the various mobility and safety applications, it is expected that CACC would benefit from its integration with other applications by taking advantage of the positive effects on traffic flow and safety that the other applications generate.

However, application co-deployment also increases the complexity of system integration and the strain on data resources. Connected vehicle-based applications and systems are undeveloped and thus risky. Introducing applications simultaneously might multiply this risk.

2.3.3 CACC Near-Term Requirements Achievability

This section presents the near-term CACC requirements that were identified in Task 3 (*Functional and Performance Requirements, and High-Level Data and Communication Needs for INFLO*) and provides a summary assessment of their achievability within the next few years. Refer to the Task 3 document for additional details about the requirements presented here, including associated systems and subsystems and user needs addressed.

ID	Near-Term Requirement	Priority	Achievable in Near-Term?
RC-1.1.3	The driver interface system shall alert the driver of the transfer of longitudinal control when entering a CACC platoon or CACC-enabled managed lane.	H	Yes
RC-2.1	The Connected Vehicle-based CACC application shall communicate the current speed and gap policy to the driver interface system for display to the driver.	H	Yes
RC-2.2	The Connected Vehicle driver interface system shall provide a means for the driver to accept, reject, and modify a given speed and gap policy.	H	Yes
RC-2.3	The Connected Vehicle-based CACC application shall modify the current speed and gap policy based on instructions received by the driver via the driver interface system.	H	Yes
RC-3.4	The driver interface system shall alert the driver of the restoration of longitudinal control when exiting a CACC platoon.	H	Yes
RC-4.1	The Connected Vehicle-based CACC application shall utilize secure data transmission methods when disseminating any personally identifiable information.	H	Yes
RC-4.2	The TME shall ensure that all personally identifiable information obtained from Connected Vehicles are anonymous.	H	Yes
RC-4.3	The TME shall protect systems and data from unauthorized access.	H	Yes
RC-4.4	The TME shall use secure transmission methods for disseminating target speed and gap policies.	H	Yes
RC-5.1	The Connected Vehicle-based CACC application shall communicate with the Integrated Vehicle Network Access System to gather real-time vehicle-collected data from the vehicle network.	H	Yes
RC-5.1.1a	The Connected Vehicle-based CACC application shall communicate with the Integrated Vehicle Network Access System to gather vehicle movement data (time, location, velocity, forward gap, heading, acceleration) from the vehicle network.	H	Yes

ID	Near-Term Requirement	Priority	Achievable in Near-Term?
RC-5.2	Communications between the Connected Vehicle-based CACC application and the Integrated Vehicle Network Access System shall utilize standardized data sets and communications protocols.	H	Yes
RC-6.1a	The Connected Vehicle-based CACC application shall disseminate position and movement data to other connected vehicles.	H	Yes
RC-6.1.1	The Connected Vehicle-based CACC application shall disseminate relevant vehicle data to other connected vehicles utilizing V2V communication.	H	Yes
RC-6.2	The Connected Vehicle-based CACC application shall disseminate relevant vehicle data to infrastructure systems utilizing V2I communication.	M	Yes
RC-7.1a	The Connected Vehicle-based CACC application shall have the ability to receive position and movement data from other connected vehicles	H	Yes
RC-7.1.1	The Connected Vehicle-based CACC application shall receive relevant vehicle data from other connected vehicles utilizing V2V communication.	H	Yes
RC-8.2	The Connected Vehicle driver interface system shall communicate individualized CACC information to the driver in an appropriate manner utilizing auditory, visual, or haptic alerts and on-screen messages.	H	Yes
RC-9.1	The Connected Vehicle-based CACC application shall fuse internally collected and externally received data to make speed and gap decisions.	H	Yes
RC-9.1.2	The Connected Vehicle-based CACC application shall consider inter-vehicle movements and actions when determining appropriate speed and gap.	H	Yes
RC-10.1	The Connected Vehicle shall provide an interface to the CACC application to enable and control throttle level and gear selection.	H	Yes
RC-10.2	The Connected Vehicle shall provide an interface to the CACC application to receive in-vehicle radar, camera, and sensor data.	H	Yes
RC-14.3	The Traffic Management Entity shall provide user education on the need to comply with recommended speed and gap targets.	M	Yes
RC-16.1	The TME-based Performance Monitoring Subsystem shall have the capability to conduct segment-specific and network-wide operational performance analysis.	H	Yes

ID	Near-Term Requirement	Priority	Achievable in Near-Term?
RC-16.1.1	The TME-based CACC application shall conduct operational performance analysis in terms of travel time reliability, travel delay, and throughput.	H	Maybe
RC-16.1.2	The TME-based Performance Monitoring Subsystem shall conduct operational performance analysis utilizing meso- and micro-simulation.	M	Yes
RC-16.2	The TME-based Performance Monitoring Subsystem shall generate trends and historical performance reports.	H	Yes
RC-16.3	The TME-based Performance Monitoring Subsystem shall have the capability to assess the reliability of data.	H	Maybe
RC-16.4	The TME-based CACC application shall be modifiable such that algorithms and software performance can be improved.	H	Maybe
RC-16.5	The TME-based Performance Monitoring Subsystem shall continuously compare the actual performance of the system with the performance determined by the CACC application to determine recommended calibrations to the application.	H	Maybe

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