MMITSS Final ConOps

Concept of Operations

University of Arizona (Lead)
University of California PATH Program
Savari Networks, Inc.
SCSC
Econolite
Volvo Technology

Version 3.0
(Final Submission)

10/21/2012

RECORD OF CHANGES

A – Added, M- Modified, D - Deleted

Version Number	Date	Identification of Figure, Table, or Paragraph	Title or Brief Description	Change Request Number
1.0	7/15/12	N/A	Initial Draft submitted for review and feedback.	CDRL 102
2.0	9/14/12	All	Address incomplete sections. Incorporate Stakeholder inputs from 7/18/12 meeting. Does not include PFS Panel review.	
3.0	10/21/12	All	Final ConOps version including reconciliation of PFS Panel comments on Revised ConOps. (See: PFP_ConOpsReconciliation.pdf for details on responses to individual PFS Panel comments)	CDRL 115

1 Purpose of Document 6
2 Scope of Project 6
3 Referenced Documents 7
4 Background 7
4.1 MMITSS Structure 8
4.1.1 Intelligent Traffic Signal System (ISIG) 8
4.1.2 Transit Signal Priority 8
4.1.3 Pedestrian Mobility 9
4.1.4 Freight Signal Priority 9
4.1.5 Emergency Vehicle Priority 9
4.2 Limitations of Current and Past Implementations 9
4.3 MMITSS Path Forward 10
5 Concept for the Proposed System 11
6 User-Oriented Operational Description 14
7 Operational Needs 16
8 System Overview 18
9 Operational Environment 24
9.1 Operational Environment Assumptions 24
9.2 Operational Environment Description 26
9.3 Policy and Institutional Issues 27
9.3.1 Safety Considerations 27
9.3.2 Data and Information Security 27
9.3.3 Data Archiving 28
9.3.4 Allocation of Signal Priority 28
9.3.5 Location of Priority Control 28
9.3.6 Authorized Nomadic Devices 29
10 Support Environment 29
10.1 Arizona Testbed 30
10.2 California Testbed 31
11 Operational Scenarios 33
11.0 MMITSS Operational Scenario 33
11.0.1 Network Section 1 34
11.0.2 Network Section 2 35
11.1 Intelligent Traffic Signal System Scenarios 37
11.1.1 Basic Signal Actuation 37
11.1.2 Coordinated Section of Signals 39
11.1.3 Congestion Control 40
11.1.4 Dilemma Zone Protection 42
11.2 TSP Operational Scenarios 43
11.2.1 Basic TSP Scenario and Variations 44
11.2.2 Operational Scenarios for Rail Crossings in Urban Areas 45
11.2.3 Extended TSP Scenario 46

11.3 Pedestrian Mobility Operational Scenarios ... 46
11.3.1 Unequipped Non-Motorized Traveler ... 47
11.3.2 Equipped Non-Motorized Traveler ... 47
11.3.3 Equipped Bicyclist ... 48
11.3.4 Inclement Weather Accommodations for Non-Motorized Travelers ... 49
11.4 Freight Signal Priority Operational Scenarios ... 49
11.4.1 Basic Freight Signal Priority ... 50
11.4.2 Coordinated Freight Signal Priority along a Truck Arterial ... 51
11.5 Emergency Vehicle Priority ... 51
11.5.1 Single Intersection Priority/Preemptions ... 51
11.5.2 Route Based Intersection Priority/Preemption ... 52
12 Summary of Impacts ... 53
12.1 Impacts to System Users ... 53
12.2 Impacts to System Owners and Managers ... 53
12.3 Impacts to System Operators ... 53
12.4 Impacts to System Interfaces ... 53
12.5 Shared and Cross-Cutting Impacts ... 53
12.5.1 Shared Impacts: System Owners and Operators ... 53
12.6 Impacts to the Transportation Field ... 54
12.6.1 Enhancements and Extension of Capabilities ... 54
12.6.2 Access to New Data Sources ... 54
12.7 Assessment of System Performance ... 54
12.7.1 ISIG Metrics and Performance Measures ... 54
12.7.2 TSP Metrics and Performance Measures ... 55
12.7.3 Pedestrian Mobility Metrics and Performance Measures ... 56
12.7.4 Freight Signal Priority Metrics and Performance Measures ... 56
12.7.5 Emergency Vehicle Priority Metrics and Performance Measures ... 56
12.7.6 Cross-Cutting Performance Measures ... 57
13 Appendices ... 58
13.1 Acronyms ... 58
13.2 References ... 60
13.3 Operational Scenario Use Cases ... 61
13.3.1 ISIG Use Cases ... 61
13.3.2 TSP Use Cases ... 67
13.3.3 Pedestrian Mobility Use Cases ... 74
13.3.4 Freight Signal Priority Use Cases ... 78
13.3.5 Emergency Preemption Use Cases ... 81
13.4 Stakeholder Input Traceability Matrix ... 82
13.4.1 Stakeholder Input Traceability Matrix – ISIG ... 82
13.4.2 Stakeholder Input Traceability Matrix – Transit Signal Priority ... 86
13.4.3 Stakeholder Input Traceability Matrix – Pedestrian Mobility ... 89
13.4.4 Stakeholder Input Traceability Matrix – Freight Signal Priority ... 92
13.4.5 Stakeholder Input Traceability Matrix – Emergency Vehicle Preemption ... 95
13.4.6 Stakeholder Input Traceability Matrix – Other ... 98
13.4.7 Stakeholder Input Traceability Matrix – Cross-Cutting Issues ... 100

List of Figures

Figure 1 – MMITSS Tasking and Path Forward ... 11
Figure 2 – MMITSS Conceptual Architecture (UML) ... 19
Figure 3 – MMITSS Transportation Management Actors ... 21
Figure 4 – MMITSS Equipped and Unequipped Actors ... 22
Figure 5 – Typical MMITSS Operational Environment ... 24
Figure 6 – MCDOT SMARTDrive Test Network ... 31
Figure 7 – El Camino Real Connected Vehicle Test Network ... 32
Figure 8 – A MMITSS System Organized into Two Network Sections for Traffic Management ... 34
Figure 9 – Active Architecture Nodes for Unequipped Signal Actuation ... 37
Figure 10 – Active Architecture Nodes for Single Equipped Vehicle Signal Actuation ... 38
Figure 11 – Active Architecture Nodes for Multiple Equipped Vehicle Signal Actuation ... 39
Figure 12 – Active Architecture Nodes for Coordinated Section Scenario ... 40
Figure 13 – Active Architecture Nodes for Congestion Control Scenario ... 41
Figure 14 – Active Architecture Nodes for Dilemma Zone Scenario ... 43
Figure 15 – Active Architecture Nodes for TSP Scenarios ... 44
Figure 16 – Active Architecture Nodes for Unequipped Non-Motorized Traveler ... 47
Figure 17 – Active Architecture Nodes for Equipped Non-Motorized Traveler ... 48
Figure 18 – Active Architecture Nodes for Basic Freight Signal Priority ... 50
Figure 19 – Active Architecture Nodes for Emergency Vehicle Priority ... 52

List of Tables

Table 1 – User-Oriented Operational Benefits ... 16
Table 2 - Summary of Responsibilities of System Component ... 23
Table 3 - ISIG Performance Measures and Metrics ... 55
Table 4 - TSP Performance Measures and Metrics ... 55
Table 5 – Pedestrian Mobility Performance Measures and Metrics ... 56
Table 6 – Freight Signal Priority Performance Measures and Metrics ... 56
Table 7 – Emergency Vehicle Priority Performance Measures and Metrics ... 56
Table 8 – Cross-Cutting Performance Measures and Metrics ... 57

1 Purpose of Document

The Concept of Operations document, or ConOps, captures a vision and a roadmap for the development, deployment, operation and maintenance of future Multi-Modal Intelligent Traffic Signal Systems (MMITSS) based upon stakeholder views and is written so that it can be reviewed and understood by the various stakeholder communities, including users, owners, operators, and benefactors. The ConOps identifies and defines goals to support a transformation of traffic signal control from today's technology into a safer, more efficient, and demonstrable system for the future. The initial MMITSS prototypes will be compatible with deployments on the existing Arizona and California testbeds, which incorporate different underlying technologies. These testbeds provide the initial validation of the feasibility of the MMITSS and initial verification of the system design. As such, the ConOps identifies opportunities for early deployment and adoption as an enabling methodology and design supporting wide scale technology adoption.

From this point on in the MMITSS documentation, the term "Stakeholder" is defined to be a definitive MMITSS user, owner, operator, or benefactor, which is indicated by the capitalization of the word as in reference to a proper noun. The Stakeholder is the focus of this document and the resulting MMITSS design.

2 Scope of Project

The Multi-Modal Intelligent Traffic Signal System (MMITSS) project is part of the Cooperative Transportation System Pooled Fund Study (CTS PFS) entitled "Program to Support the Development and Deployment of Cooperative Transportation System Applications." The CTS PFS was developed by a group of state and local transportation agencies and the Federal Highway Administration (FHWA). The Virginia Department of Transportation (VDOT) serves as the lead agency and is assisted by the University of Virginia's Center for Transportation Studies, which serves as the technical and administrative lead for the PFS.

The United States Department of Transportation (US DOT) has identified ten high-priority mobility applications under the Dynamic Mobility Applications (DMA) program for the connected vehicle environment where high-fidelity data from vehicles, infrastructure, pedestrians, etc. can be shared through wireless communications. Three of the applications (Intelligent Traffic Signal System, Transit Signal Priority, and Mobile Accessible Pedestrian Signal System) are related to transformative traffic signal operations. Since a major focus of the CTS PFS members – who are the actual owners and operators of transportation infrastructure – lies in traffic signal related applications, the CTS PFS team is leading the project entitled "Multi-Modal Intelligent Traffic Signal System" in cooperation with US DOT's Dynamic Mobility Applications Program.

The MMITSS project is divided into four technical segments. The development of the ConOps, including the solicitation of Stakeholder inputs and feedback, is the first technical stage. The reviewed Stakeholder inputs and ConOps are used to develop, define, and populate the MMITSS system requirements in the second technical stage. In the third stage, the system requirements and prior research are used to define the MMITSS system design. The design effort will utilize the California Test Bed and the Maricopa County Test Bed as the target implementation networks. Implementation, integration, deployment, and test plans based on this design will be defined in the final stage. From this process description, the importance of the clarity, accuracy, and completeness of the ConOps is evident.

3 Referenced Documents

External and public released information used or referenced in this document is listed in the References Appendix in Section 13.2. The MMITSS project documentation used or referenced in this report is shown below:

- PFP[1] Assessment of Prior and Ongoing Research (Submitted 6/29/12)
- DRAFT PFP Stakeholder Input Report (Submitted 6/30/12)
- PFP Stakeholder Meeting Materials (Submitted 5/31/12)

4 Background

Traditional approaches to traffic signal control have been based on low fidelity detection and less intelligent control systems that typically are not well informed about the state of the traffic and are not necessarily modally aware. Use of special devices for emergency vehicles and transit are exceptions. In general, the presence of pedestrians and other users of the system have been known only by the issuance of a call (from pedestrian push button or vehicle detector). The advent of connected vehicle (CV) technology and systems provides the first real opportunity for multi-modal control where intelligence can be used to provide cooperative services and priority to each mode. These modes include general passenger vehicles, pedestrians, transit, freight, and emergency vehicles.

Connected vehicle technologies enable vehicles to exchange information with each other and with the roadside infrastructure in real time. These technologies also enable nomadic devices such as smart phones and tablets carried by pedestrians and bicyclists to exchange real-time information about their movements with the roadside infrastructure. At the national level, when the Vehicle-Infrastructure Integration (VII) program began work on what is now known as connected vehicle technologies, the focus was entirely on the use of 5.9 GHz dedicated short-range communication (DSRC) technology. In recent years, the focus has broadened to include a full array of wireless technologies such as 3G and 4G/LTE cellular, WiFi, and Bluetooth. Throughout this report, the mobile devices in vehicles are referred to as Onboard Equipment (OBE), those carried by non-motorized travelers are referred to as nomadic devices, and infrastructure-based devices are referred to as Roadside Equipment (RSE). Although these terms were originally associated with DSRC technology, here they can refer to any of the wireless technologies.

In a connected vehicle environment, signal priority for multiple vehicles with different modes (transit, freight and emergency) can be managed within an integrated framework. Vehicles that are eligible for signal priority communicate their desired level of priority information to the roadside infrastructure. The allocation of priority levels is determined by involved Stakeholders (e.g., local agencies, transit operators, and freight operators) enabling the effective management of signal priority control through inputs to MMITSS. Different levels of priority for eligible vehicles, whether multi-modal or within the same mode, can be assigned based on the local interpretation of signal priority importance and usefulness. For example, emergency vehicles in Active Response Mode should have a higher level of priority than transit and freight vehicles; a transit vehicle with a higher passenger load that is farther behind schedule can be assigned a higher level-of-priority than a bus with fewer passengers that is not as far behind schedule; freight

[1] PFP or the Pooled Fund Project was the original designation of the MMITSS project funded and managed through the Pooled Fund Study (PFS) and Panel.

vehicles can be assigned a higher level of priority than transit vehicles along a truck corridor where the truck volume is high. Implementing levels of priority provides the flexibility to configure the policy for signal priority control based on the local or regional characteristics and transportation management goals. MMITSS will process multiple requests for priority, assess the prevailing traffic conditions, and execute the most appropriate priority strategy to accommodate the requests while limiting the negative impacts on general traffic.

4.1 MMITSS Structure

The MMITSS project provides the foundational analysis (Stakeholder Input Solicitation, ConOps, and System Requirements) and design (conceptual design, implementation plan, integration plan, and test plans) necessary to prepare for the development and field testing or demonstration of an MMITSS. The MMITSS is defined as a comprehensive traffic signal system taking advantage of the connected vehicle environment for multiple transportation modes, including general passenger vehicles, transit, pedestrians, freight vehicles, and emergency vehicles. The MMITSS incorporates, at a minimum, the arterial traffic signal applications identified through the DMA template process of US DOT. Brief descriptions of these applications, modified from the DMA applications description document, are provided below:

4.1.1 Intelligent Traffic Signal System (ISIG)

The use of high-fidelity data collected from vehicles through wireless communications will facilitate accurate measurements and predictions of lane-specific platoon flow, platoon size, and other driving characteristics. Real-time data availability has the potential to transform how traffic signal systems are designed, implemented, operated, and monitored. Developing new systems that use data via V2V and V2I wireless communications to control signals to maximize flows in real-time can improve traffic conditions significantly. The Intelligent Traffic Signal System or ISIG plays the role of providing the underlying functionality of the MMITSS operations by virtue of its control and connectivity with the traffic signal control. This can be integrated into an over-arching system optimization application, accommodating transit or freight signal priority, preemption, and pedestrian movements to maximize overall arterial network performance. In addition, the interface (i.e., traffic flow) between arterial signals and ramp meters (essentially traffic signals installed on freeway on-ramps) should be considered. Note, however, that the development of ramp metering algorithms — the metering rates to optimize freeway flow — is not included in the scope of this application.

4.1.2 Transit Signal Priority

Transit Signal Priority (TSP) strategies adjust signal timing at intersections to better accommodate transit vehicles. Connected vehicle technologies provide opportunities to significantly enhance current TSP systems; (1) provide more accurate estimates of prevailing traffic conditions at signalized intersections by integrating conventional loop detector data and wireless data; (2) allow earlier detection and continuous monitoring of transit vehicles as they approach and progress through intersections; and (3) support more intelligent priority strategies that implement trade-offs between traffic and transit delay at intersections in a network. In a connected vehicle environment, transit vehicles can transmit data characterizing the need for priority (i.e., the level of priority) to the roadside infrastructure. It is now possible to provide “differential” priority, whereby different levels of priority can be granted to multiple transit vehicles depending on a number of factors, including prevailing traffic conditions, current status of the traffic signal controller, and the status of each transit vehicle.

4.1.3 Pedestrian Mobility

MMITSS will facilitate pedestrian mobility at intersections by meeting pedestrians' special needs or by balancing utilization of the intersection by vehicles and pedestrians. This application will integrate traffic and pedestrian information from roadside or intersection detectors and new forms of data from wirelessly connected, pedestrian-carried mobile devices (nomadic devices) to request dynamic pedestrian signals or to inform pedestrians when to cross and how to remain aligned with the crosswalk based on real-time Signal Phase and Timing (SPaT) and MAP information. In some cases, priority is given to pedestrians, such as persons with disabilities that need additional crossing time, or in special conditions (e.g., weather or special events) when pedestrians may warrant priority or additional crossing time. This application will enable a "pedestrian call" to be routed to the traffic signal controller from the nomadic device of a registered person with disabilities after confirming the direction and orientation of the roadway that this pedestrian is intending to cross. The MMITSS will be able to manage pedestrian crosswalks when certain predetermined conditions occur in order to improve the efficiency of intersection utilization or to avoid overcrowding pedestrians at curbs in large downtown areas or at special events such as sporting events or concerts.

4.1.4 Freight Signal Priority

In a CV environment, signal priority techniques for transit can be applied to freight vehicles to grant right-of-way over general traffic. Priority strategies for freight can consider the special operating characteristics associated with freight vehicles. For example, freight vehicles require greater stopping distance than passenger cars and the severity of accidents is greater when they are unable to stop at red signals. After stopping, additional time and fuel is required to resume nominal travel speeds due to vehicle dynamics, which can impose delays to surrounding vehicles. The goals of freight signal priority include reduced stops, reduced delays, and increased travel time reliability for freight vehicles, which can reduce negative environmental impacts, reduce pavement damage, and enhance safety at intersections. MMITSS utilizes an integrated framework to respond to priority requests from freight vehicles to better accommodate the collective needs of multi-modal travelers.

4.1.5 Emergency Vehicle Priority

Emergency Vehicle Priority (EVP) provides a very high level of consideration for emergency first responder vehicles. Historically, priority for emergency vehicles has been provided by special traffic signal timing strategies called preemption. The goal of EVP is to facilitate safe and efficient movement through intersections. As such, clearing queues and holding conflicting phases can facilitate emergency vehicle movement. For congested conditions, it may take additional time to clear a standing queue, so the ability to provide information in a timely fashion is important. In addition, transitioning back to normal traffic signal operations after providing EVP is an important consideration since the control objectives are significantly different.

4.2 Limitations of Current and Past Implementations

Existing traffic control systems have accommodated different travel modes in limited ways. Vehicles have been served by signals either based on fixed signal timing, or by actuated signal timing using fixed location vehicle detection to call and extend phases and sometimes as input to adaptive traffic signal timing systems. Actuated signal control detection provides passage and presence information to the signal controller. System detectors, which provide measures of volume and occupancy, are sometimes used by traffic responsive algorithms to select signal timing plans from a library of plans developed for a variety of traffic conditions. System detectors are also used by some adaptive control systems. Pedestrians are served almost exclusively by pedestrian push buttons or by programming the signal controller to recall the pedestrian intervals every cycle. Recently, there have been improvements in detection of pedestrians, but this technology is not widely adopted.

Emergency vehicle preemption and transit priority systems have been implemented using a variety of detection/communications technologies that can send a message to the intersection traffic signal controller, which can be configured to provide preemption or priority. Generally, these requests are served one at a time on a first come, first served basis. A preemption request can override a priority request, but most controllers can't serve multiple requests at a time. Some research in freight signal priority has been performed, but the deployment is not widespread.

4.3 MMITSS Path Forward

The MMITSS Path Forward defines a systems engineering approach to analyzing, defining, implementing, evaluating, and testing a prototype MMITSS. As shown in Figure 1, the Assessment of Prior and Ongoing Research report identified and reviewed research related to the MMITSS. In addition to providing historical input and guidance on factors influencing the MMITSS system design, the assessment offers initial identification of key performance parameters (KPPs) and metrics that could be reapplied in the definition of transformative goals and performance measures for the proposed system. The MMITSS Stakeholder Meeting was organized around a broad selection and invitation of users, operators, owners, managers, and decision makers. Scenarios were developed and presented to solicit Stakeholder inputs, feedback, and guidance, which were documented in the MMITSS Stakeholder Input Report submitted August 1, 2012.

In this ConOps document, the information from the Stakeholder Meeting is synthesized and applied to further the specification of user preferences and needs, operational needs, relevant scenarios, restrictions and limitations on the initial MMITSS system, and impacts (both beneficial and deterrent/restrictive). Within the ConOps document, the MMITSS system definition begins taking shape in the form of a system concept, system overview, and operational description. After the material in the ConOps is reviewed and revised by the PFS Panel, the system requirements can be formulated and formalized. As part of the requirements definition process, the verification methodology is specified in the verification cross reference matrix (VCRM) and test plans are initiated. Another aspect of the requirements definition process is requirements traceability. In order to facilitate the traceability process, the Stakeholder inputs have been reorganized and reformulated as shown in the appendix (See Section 13.4). This format enables the tracking of Stakeholder input to ConOps scenario, which initiates the development of requirements.

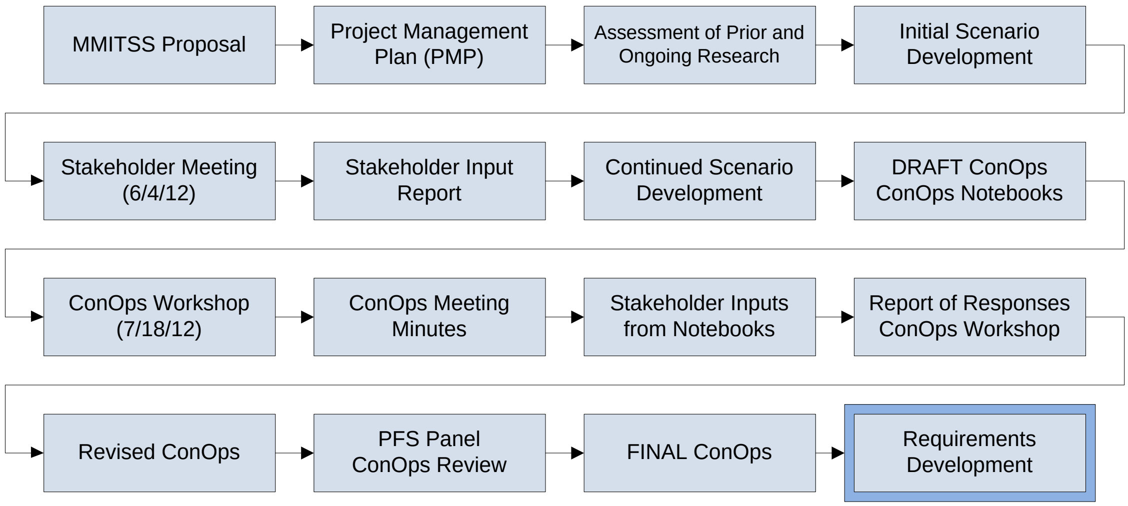

Figure 1 – MMITSS Tasking and Path Forward

5 Concept for the Proposed System

The MMITSS is envisioned to be an intelligent traffic management system that will be deployed in the 5-year time horizon and reach maturity within a 10-year time horizon. The MMITSS provides intelligent traffic signal control for both unequipped travelers and travelers that are equipped with wireless devices including smartphones, DSRC capable devices, and potentially other nomadic devices. Some of these travelers will be motorized (such as passenger cars, transit, trucks, and emergency vehicles) and others will be non-motorized (such as pedestrians and bicycles). The goal of MMITSS is to provide high quality traffic signal control to multiple modes of travelers by simultaneously optimizing operations for all of the modes.

The MMITSS supports two advanced control functions, including basic traffic control actuations and priority control. The basic traffic control actuation function assumes some vehicles and travelers are equipped and others are not equipped. The traffic signal system is aware of these travelers – either though sensors/detection or through assumed behaviors and controller programming (e.g., pedestrian recall). Basic traffic control provides actuation of phases and intervals in the traffic signal controller. Priority control considers specific requests from qualified classes of vehicles and travelers for traffic signal service based on vehicle mode, class, position, speed, and prevailing conditions, such as emergencies, disabilities, and weather conditions. Priority control enables a hierarchy of control considerations based on a policy that determines the importance of some vehicles over others, but can accommodate multiple requests for priority at any time. Coordination, or traffic signal synchronization, can be considered a form of priority control that provides progression through a series of traffic signals for a group (platoon) of vehicles.

The MMITSS design is partially driven by the traditional traffic signal control architecture and partially by the evolving connected vehicle architecture. The MMITSS will be designed and operated consistent with the architectures being developed in other dynamic mobility application (DMA) projects. The basic components of the connected vehicle system include the infrastructure based equipment (called Roadside Equipment – RSE) and the vehicle, or traveler, based equipment (called On-board Equipment (OBE) or nomadic device. Each of these components provides both communications and processing capabilities that support connectivity and intelligence for equipped travelers and vehicles.

All travelers, equipped and unequipped, can be served by the traffic control system either by being detected by field sensors (e.g., loop detectors or pedestrian push buttons) or by default programming of the traffic signal controller. In the event that there is a component failure in the connected vehicle system, the default mode of control would be to treat all vehicles as unequipped. Equipped travelers are actively sending information about their position and speed (plus significant additional data) that can augment and enhance the field sensor data. This new information is used to improve basic traffic signal operations as well as in the assessment of performance. Equipped travelers can be tracked by the MMITSS when they are within communications range of infrastructure-based equipment. Unequipped vehicles are monitored only at fixed detector locations. This additional information will allow intelligent traffic control logic to better serve the different modes of travelers.

MMITSS will operate the actuated and coordinated behavior of traffic signals, groups of traffic signals (called sections), and systems of traffic signals to better adapt to prevailing conditions at the intersection level, section level, and system level. Traditional signal control is generally based on standard detector layouts that rely on agency standards and intersection design speeds. As traffic demands vary and vehicles travel and queue in a stochastic manner, these assumptions may not result in the best possible control. Equipped vehicle data, in conjunction with traditional detection, can be used to mitigate some of these assumptions. Examples include the call and extension of phases by different classes of vehicles (passenger vehicles, freight trucks, etc.). Another is in the protection of different modes of vehicles on high-speed approaches, called dilemma zones, especially when the environmental conditions could impact vehicle dynamics. Similarly, coordinated signal operations are dependent on selection of pattern parameters including cycle length, offset, and phase splits based on design volumes and speeds. These factors can vary on a daily basis and the performance can be measured and improved. Equipped vehicle data can be used to assess the performance of the coordinate pattern and to make adjustments in critical timing parameters.

Some equipped travelers, including emergency vehicles, transit, freight trucks, and pedestrians can actively participate in requesting special service considerations (e.g., priority) by the traffic signal controller. These equipped travelers will be capable of transmitting a request for service message to intersections as they travel their intended route. The request for service message contains information about the mode, vehicle class, priority level, and desired time of service. The signal control system will have the ability to send service status messages, or confirmations, about the future signal timing plan to allow requesting travelers to know their status in the priority request scenarios. This is a significant enhancement over priority systems used today.

An important and new capability of MMITSS is the management of multiple requests for priority that may be received from multiple vehicles, as well as multiple modes, at any time. These requests can come from emergency vehicles that are responding to an incident (or several incidents), transit vehicles, freight vehicles, bicyclists, and/or pedestrians. To manage these multiple requests, MMITSS will provide a hierarchical level of priority that can facilitate regional policies and preferences for priority control. For example, an agency may decide that emergency vehicles are given priority levels two (2) through four (4), where two (2) is assumed to have higher priority than four (4). Fire vehicles may be assigned to a level two (2), ambulances a level three (3), and police a level four (4), if there is a critical event that requires the police to respond as quickly as possible, such as a person with a weapon at a school or shopping center, they may be given a level two (2) priority. Similarly, transit may be assigned levels five (5) through nine (9) where the level of priority depends on the class of service (BRT, Express, or local) as well as other factors such as lateness and passenger occupancy. The fleet management system and the vehicle have the opportunity for determining the priority level for the vehicle before it communicates the request for service to the traffic control system (MMITSS). Freight and pedestrians might be assigned lower levels of priority. It is assumed that rail and cable cars are provided the highest level of priority (or preemption) due to the special characteristics associated with their operation (track clearance, gates down, dwell, free-running etc.). [Note: this structure and definition is consistent with NTCIP 1211 – Object Definitions for Signal Control and Prioritization].

The MMITSS design will support interfaces to the connected vehicle system (RSE), existing traffic control equipment and management system, new traffic control technology with evolving new sensors and detection technology, and other dynamic mobility applications. The interface between the traffic signal control equipment and the RSE is the fundamental channel for control coordination. Recently, FHWA has developed a MAP and SPaT interface for modern traffic signal controllers that provides signal controller status in a format consistent with the NTCIP standards. The SPaT interface includes the ability for inputs to the controller as well, but it may be necessary to extend this interface to include priority requests and to utilize existing priority related objects (NTCIP 1211) and other ASC control objects (NTCIP 1202). In addition to the basic interface to the controller, MMITSS will collect performance data for use in intelligent control logic, which will be made available to the traffic management system. This interface will be designed to conform to the traffic management data dictionary (TMDD) as well as NTCIP standards. These two interfaces are critical to the integration of MMITSS with existing traffic control and management systems.

Advances in sensor and detection technology in the next 5 to 10 years are likely to result in information that will be valuable to MMITSS as well as other connected vehicle applications. For example, emerging developments in sensor and detector technology are producing sensors for tracking objects in the roadway (MMITSS ConOps Meeting July 18, 2012, p. 10 – GD). This information could be used to enhance and validate the connected vehicle component (RSE) that is tracking BSMs from equipped vehicles. Hence, there needs to be an interface between the RSE and these new sensors. It is anticipated that this interface will be defined in a cooperative fashion with sensor developers and will conform to national communication standards (e.g., NTCIP).

A key future capability will be the interface between MMITSS to other dynamic mobility applications, such as speed harmonization and applications that monitor environmental (weather) conditions. Applications such as speed harmonization can provide significant benefits to MMITSS, resulting in effective coordination in a signalized section and in mixed mode operations, such as in a freight corridor. The ability to coordinate vehicle speeds will provide MMITSS the ability to better provide progression, smoother and safer traffic flow, and service to transit and freight vehicles. Information from applications that monitor environmental conditions can augment environmental data that could be collected locally (e.g., environmental sensor) for the purpose of decision making for dilemma zones and freight priority, as well as in choosing coordination plans. It is assumed that other dynamic mobility applications will be developed that can provide benefits to MMITSS as well and that their value to MMITSS can be determined as they are developed and integrated.

In summary, the key capabilities described in this section facilitate the goal of the MMITSS to provide high quality traffic signal control to various roadway users by simultaneously optimizing operations for all of the modes: private vehicles, pedestrians, transit, freight, and emergency vehicles.

6 User-Oriented Operational Description

Simplistically, the MMITSS users include anyone who will come into contact with a signalized intersection whether they are walking, driving, riding, maintaining, overseeing, or monitoring within or near the intersection. The users include the general public, public workers and administrators, traffic signal system operating agencies, transit providers, emergency service agencies, and commercial freight operators. These transportation users, whether in an urban or rural area, participate in the technological advancements associated with the Information Age through cell phones, smart phones, mobile GPS devices (e.g., Garmin, TomTom), OnStar, and related devices or services. It seems reasonable for the public to expect that traffic signal control has benefitted from related technological advancements. Yet, according to a study performed by the Texas Transportation Institute[2] of 439 urban areas in the US, commuters spend an average of 36 hours annually idling in traffic.

The driving public wants traffic signals that can “know” or “see” that: (i) their car is waiting for the traffic signal to turn green, while there isn’t another vehicle or pedestrian in sight; (ii) the icy roadway is making it harder to stop at the yellow light; (iii) much of the traffic leaving the baseball stadium will traveling specific arterial routes in order to reach the freeway; and many other seemingly obvious opportunities for improved performance.

The walking or cycling public wants traffic signals that “know” or “see” that: (i) crosswalks by major universities or in downtown metropolitan areas are utilized more or at different times than those in rural areas; (ii) as an aging public, decreasing or changing mobility and eyesight are requiring additional crossing time and assistance; and (iii) as the price of fuel increases, more people will rely on alternative transportation such as walking, bicycles, and transit; and many other seemingly obvious opportunities for assisting the non-motorized traveler.

The transit rider interacts with the signalized intersection in ways that offer opportunities for enhancement: (i) information on the expected time of arrival of the next bus, rather than stepping out into traffic to view if the bus is on the way, (ii) updated information on a connection while sitting on a traveling transit vehicle, (iii) bus scheduling based on realistic, observable, and seasonal data; and numerous other desirable improvements. Traffic signals contribute significantly to the delay of buses and priority can provide a mechanism for a bus that is behind schedule or running behind the planned headway to get back in step. Providing reliable transit service is a transportation system goal and is one that make transit an attractive travel mode.

The freight operator and company interact with signalized intersections in a slightly more complex manner offering broader opportunities for enhancement. Not only do they assume direct “user” interactions with the system of signalized intersections, their use of the public roadway imposes greater interactions with and requirements on transportation operating agencies, such as street maintenance due to increased pavement wear imposed by transporting heavy loads. From a direct user perspective, freight operators and supporting fleet management system operators want traffic signals that “know” or “see” (i) the consequences of idling at a traffic signal or series

[2] Texas A&M University

of traffic signals influences the cost of goods, diminishes local air quality, and impacts the pavement lifespan due to acceleration and deceleration of loaded vehicles, and greater engine and exhaust heat as well as noise; (ii) with all the technological advancements, the status of the signalized intersections and roadway sections should be readily available to the freight dispatch center (a Fleet Management System, FMS) for routing and rerouting decisions; (iii) when a large freight vehicle is delayed at intersections, queues of other types of vehicles are more likely to form compounding the delay and decreasing the freight vehicle maneuverability due to obstacles; (iv) cargo is heterogeneous (e.g., perishable, express, Hazmat), which affects the transportation objective beyond getting from an origin to a destination; and numerous other desirable improvements.

"First responder" is a term describing those MMITSS users dedicated to providing emergency services to enhance the quality of life for the general public. First responders include firefighters, police, sheriff, highway patrol, paramedics, react personnel, and civil defenders (e.g., National Guard and US Border Patrol agents). Unlike the previously described system users, first responders interact with signalized intersections for the sole purpose of providing emergency services to others (i.e., the public). As such, it is imperative that they receive safe and effective prioritized service at these intersections and roadway sections.

First responders interact with the system in ways more complex than freight, transit, or passenger vehicles: (i) costs associated with traffic delays are greater than loss of productivity or inconvenience – the costs can be measured in loss of life or limb if they arrive at an incident too late to render help; (ii) since most emergencies are multi-faceted, various emergency vehicles will approach the incident site from nearly all directions, resulting in safety concerns when transitioning through nearby intersections even after priority has been granted; (iii) as the demands on the transportation infrastructure exceed design capacity, first responders need to rely on an intelligent system to alleviate queues and congestions permitting the maneuvering of emergency vehicles around traffic; (iv) while traveling to an incident, first responders need to rely on effective dispatch operations that could benefit from real-time status information from nearby roadside equipment; and numerous other enhanced interactions with signalized intersections.

Regardless of the type of transportation user, the desires imposed on a modern traffic signal system share similar characteristics - Allow the user to access and participate with the system faster, safer, and better in ways listed in Table 1 and described and quantified in Section 12.7. These entries were compiled using specific Stakeholder inputs on the desired MMITSS operational behavior found in Section 13.4. But before leaving this section on the user-oriented operational descriptions, it is fitting to quote a Stakeholder at the MMITSS ConOps Workshop[3] when describing the underlying issue and complexity of the MMITSS project. "It's great to have all these theoretical decisions, but in reality you have to make tradeoffs. You've got to balance the operations (*i.e., ISIG, Pedestrians, Transit, Freight, and Emergency Vehicles*) for greater performance."

[3] MMITSS ConOps Workshop held on 7/18/12 at AASHTO in Washington, DC.

	Faster	Safer	Better
Non-Motorized Traveler	- Improved Response Time - Reduced Delay Time - Trip/Route/Navigation Pre- Planning	- Reduced Crosswalk Encroachment - Responsive to Disabilities - Responsive to Weather Conditions - Reduced Jaywalking Occurrence	- Improved Ease of Use - Enhanced/ Anticipatory Behavior
Motorized Vehicle (General)	- Reduced Travel Time - Reduced Travel Time Variability - Reduced Queue Length - Reduced Degree of Saturation - Reduced Extent of Congestion - Reduced Temporal Duration of Congestion - Data-driven Performance Metrics and Feedback	- Reduced Red-Light Running - Reduced Incidents/Accidents - Advanced Notice of Traffic Incident or Accident	- Situational Responsiveness - Increased Throughput - Accessibility of Data and Data Analyses - Improved System Reliability Improved System Maintainability/ Supportability - Signal/System State of Health Monitoring - Reduced Emissions
Transit Specific	- Reduced Average Transit Delay - Reduced Transit Delay Variability - Improved Connections	- Reduced Jaywalking Occurrence during Connections	- Improved Transit Ridership - Increased Customer Satisfaction - Reduced Per Traveler Emissions
Freight Specific	- Reduced Overall Truck Delay - Reduced Signalized Stop Duration/Delay	- Reduced Freight-Intersection Accidents - Reduced Dilemma Zone Incursions	- Improved Energy/Fuel Savings - Improved Freight/Goods Reliability - Improved Delay Management - Reduced Pavement Wear - Reduced Emissions
Emergency Vehicle Specific	- Reduced Overall EV Delay - Reduced EV Delay Variability	- Reduce EV Accident/ Incidents at Intersections - Arrival at Incidents/ Accidents in Time to Render Aid	- Improved EV Response Time

Table 1 – User-Oriented Operational Benefits

7 Operational Needs

The goal of MMITSS is to provide a cooperative and optimizing system that simultaneously considers multiple modes of travel within an integrated control framework. The connected vehicle system provides a data rich environment for improving safety and efficiency of traffic signal systems. This information provides the opportunity to use knowledge about all modes of travelers – including their position, trajectory, and status.

For the first MMITSS Stakeholder Meeting 55 participants were invited to participate and provide input on User needs and system design considerations. A total of 35 participants provided inputs and feedback, including representatives from federal, state, and local transportation departments, transit operations, freight vehicles and movement, emergency management, and traffic equipment suppliers and solution providers. The meeting webinar format allowed a broad and expert group of participants to consider the design of a multi-modal intelligent traffic signal system and to provide valuable input to the project team.

There are several themes that evolved from the webinar. First, there seems to be consensus that there is clearly a need for an intelligent traffic signal control system that considers multiple modes of travel in an integrated and cooperative system (impacts MMITSS Conceptual Architecture and Framework). The participants were in agreement that the connected vehicle environment offers a data rich environment that can lead to system and performance enhancements. The data will assist in the assessment and verification of performance improvements. Numerous comments reiterated the need to share and protect this data (Policy and Institutional Issues Section 9.3).

While the scenarios were presented by mode (vehicles, transit, pedestrians, freight, and emergency vehicles), the participants suggested that priority control is very similar for transit, freight, and emergency vehicles. There was one participant that noted that the Freight Priority assumptions might not be consistent with the industry operating principles since data may not be readily shared due to competitive advantage considerations.

Next, there was some concern about the dependence on DSRC technology and the emerging capabilities of 3G/4G wireless communications. These other communication systems may satisfy the communication needs of a MMITSS, perhaps better than DSRC. These comments impact the development of the Concept of Operations and System Requirements so that the System Designs considered have sufficient separation between the functionality and the communication technologies that might be used in the future implementations (e.g., Arizona and California Testbeds). In addition to the technical aspects of the communications interface utilized in the MMITSS project, several Stakeholders provided comments and cautions on equipment maintenance, system availability, and adequate staffing and training.

Throughout the Stakeholder Meeting and corresponding written comments, the underlying relationship between the MMITSS project and other safety-related applications was noted by many of the meeting participants. These safety-related comments spanned the pedestrian, transit, EV, and freight scenarios. As such, the interplay between the safety aspects and MMITSS Project was presented at the MMITSS ConOps Workshop. The recommendation of the Concept of Operations Workshop was to note the safety issues in the MMITSS ConOps, but do not inhibit the progress of the MMITSS research effort due to excessive consideration of safety issues, safety considerations, or safety testing on the project scope (See: PFS_ConOpsMeeting_071812.pdf).

Performance measures, metrics, and goals received substantial review and feedback. There was a clear divide on which performance measures should be evaluated and whether any performance measures should be identified in a project with such a research bent. Whereas some of the suggested measures may be outside the scope of this effort, the authors are in agreement that a subset of performance measures should be defined, maintained, and evaluated to show potential benefits and possible difficulties of operating in a connected vehicle environment. Some definition and selection of performance measures is required for demonstrating the collection and updating within the MMITSS architecture.

The Stakeholder feedback and inputs are presented in synthesized groupings in Section 13.4 and in the Report of Responses from ConOps Workshop[4]. This feedback is mapped to the ConOps, scenarios, and use cases as shown in the third column of the tables. This permits rapid verification that each of the Stakeholder comments was considered during the development of the ConOps. The User needs are developed into scenarios (Section 11) and use cases (Section 13.3).

8 System Overview

The purpose of the MMITSS is to integrate new information from connected travelers and existing information from infrastructure based detection systems into a safer and more effective traffic signal control system. This integrated information can be used to make improvements in traffic control algorithms and logic resulting in better performing and safer operating systems. In addition to enhancing traffic control algorithms and logic, information from connected vehicles can be used to directly measure system performance and for the assessment of safety.

There are several vehicle and vehicle-infrastructure based applications to address safety directly, such as the Cooperative Intersection Collision Avoidance Systems (CICAS). These applications use signal phase and timing (SPaT) data to make vehicle based safety decisions. Simple traffic signal logic, such as lengthening the yellow or red clearance interval, has been investigated as part of these applications (Grembek and Zhang/PATH). For the purpose of development of MMITSS it is assumed that these applications are responsible for safety features and that they may interface with the traffic signal system, including MMITSS, but MMITSS is not responsible for active safety features.

The basic architecture for the connected vehicle system is being defined across a variety of USDOT efforts and the MMITSS effort is coordinating through US DOT to ensure consistency. The basic architecture is illustrated in Figure 2 as a UML Deployment Diagram. The nodes have been shaded such that the light colored nodes are part of the connected vehicle, Traffic Management, and Fleet Management systems (or nodes that can be modified or assigned MMITSS responsibilities) and the gray colored nodes represent the vehicles and travelers.

[4] MMITSS CDRL 112, PFP_ConOpsWorkshopCDRL112.pdf, 9/12/12

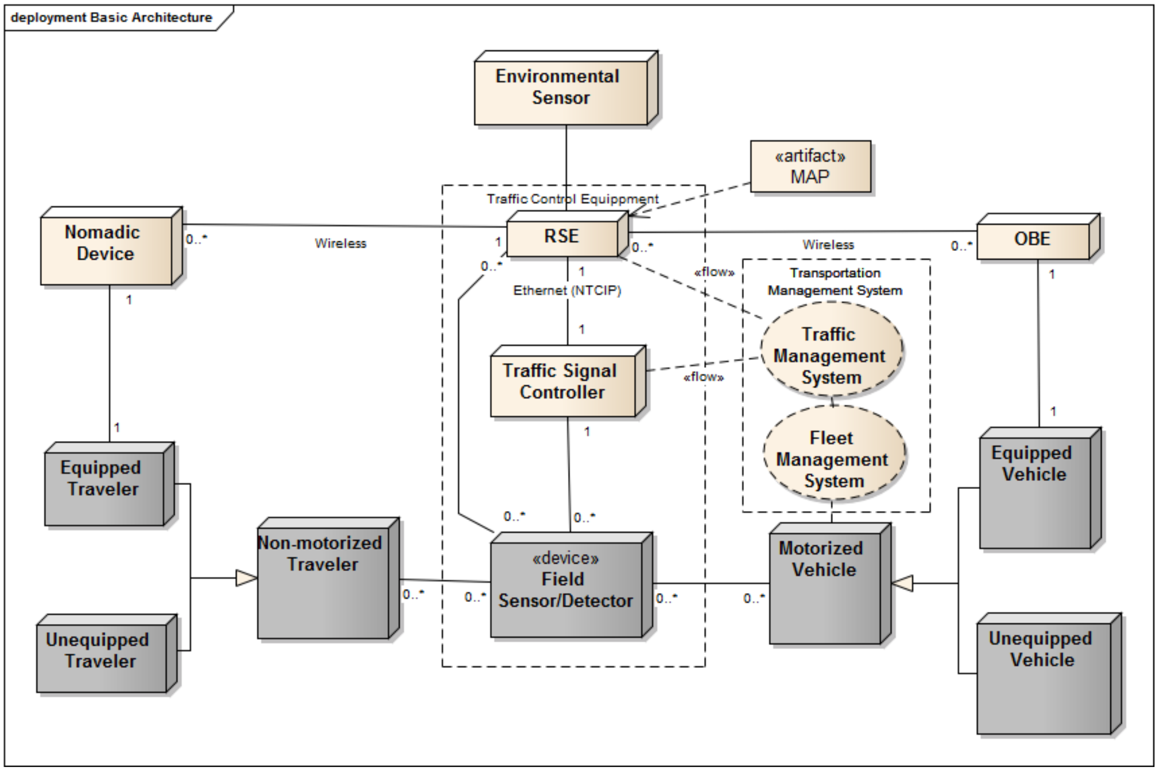

Figure 2 – MMITSS Conceptual Architecture (UML)

In this view of the system, there are two types of travelers – motorized vehicles and non-motorized travelers. Motorized vehicles consist of passenger vehicles, trucks, transit vehicles, emergency vehicles, and motorcycles. This type of traveler includes any vehicle that must be licensed to operate on the public roadway. Non-motorized travelers include pedestrian, bicyclists, and other modes such as equestrians that are not required to be licensed to operate on the public roadway. These travelers are either unequipped or equipped, meaning that they have some type of OBE or nomadic device that is CV (or MMITSS) aware and can operate as part of the traffic control system.

The anticipated system users, categorized as equipped or unequipped non-motorized travelers and/or motorized vehicles, are shown in Figure 4. The users are grouped into descriptive categories to convey the sharing of similar characteristics, traits, and needs. For example, a passenger vehicle and a non-commercial, light duty truck (e.g., Ford F-150 or Chevrolet Silverado) could be considered as one category of users. At this point in the MMITSS project, these have been defined these as two separate user categories to accommodate the difference in characteristics and traits for the case where the light duty truck could be loaded with a ton (2000 pounds) of cargo, which could impact the scenarios and use cases associated with Dilemma Zone (Section 11.1.4) and/or Congestion Control (Section 11.1.3).

An equipped traveler can be a pedestrian with a nomadic device, a pedestrian with disabilities supported by an Authorized Nomadic Device (See Section 9.3.6), or any of the users shown in the upper left portion of this figure that possess a functioning nomadic device. In comparison, the user categories comprising the category of unequipped traveler are shown. Without a nomadic device (i.e., an unequipped traveler), the MMITSS cannot distinguish between a pedestrian, pedestrian with disabilities, or bicyclist. Hence, the possible user categories for an unequipped traveler are pedestrian and bicyclist (in cases where a dedicated bicycle lane push button or bicycle detector is present).

Motorized vehicles can be part of a fleet management system such as a transit management system, commercial freight management system, emergency vehicle dispatch system, and taxi dispatch, which is shown as a UML collaboration (oval in Figure 2) meaning that a collection of entities work together to perform the traffic management functions, but there may be many different systems involved in this collaboration.

The infrastructure based traffic signal control equipment consists of the traffic signal controller, and possibly an RSE. It is possible that an RSE will not be required at every intersection and that some of the RSE functionality could be supported remotely. The traffic signal controllers can be part of a larger traffic management system that controls and organizes groups (sections) of signals. The larger traffic management system is shown as a UML collaboration in Figure 2. The RSE is a general communications processing node that coordinates messages from the various modes of travelers into traffic signal controller inputs. The RSE contains (deploys) the MAP, which is the digital description of the intersection geometry and associated traffic control definitions. The MMITSS architecture has provisions for the inclusion of both local and networked weather sensors through the Environmental Sensor node. As a physical sensor, this can take the form of temperature, precipitation, ice, wind, or similar sensor interfaces. In a networked configuration, a data interface can provide weather and environmental information without actual hardware connection to the specific sensor. Regardless of the source of the environmental data, the MMITSS can make provisions for pedestrians waiting to cross or the stopping distances of cars versus heavy trucks on icy days.

The traffic management systems (TMS) and the fleet management systems (FMS) together compose the greater transportation management system that is responsible for management of regional transportation capabilities. These systems may be distributed across government and agency boundaries, but work together to address the overall transportation needs. The actors comprising the transportation management system are shown in Figure 3.

Both motorized and non-motorized travelers can be detected by the Field Sensor/Detector node at the intersections using a variety of detection technologies, including inductive loop detectors, video detection, microwave, radar, pedestrian push button, etc. The detection system at an intersection provides information to the traffic signal controller that stimulates the control algorithms. For example, a vehicle that triggers a detector will call a signal control phase for service or extension. A pedestrian may activate a pedestrian push button to request the traffic signal pedestrian interval associated with a crosswalk movement.

Each of the systems that can be active participants in the MMITSS (e.g., connected vehicle, Traffic Management, and Fleet Management) can have different responsibilities, and in alternative system designs some of these responsibilities can be assigned to different components. In the discussion presented here, the basic operating functions will be reviewed and the alternative assignments will be explored in the detail design effort.

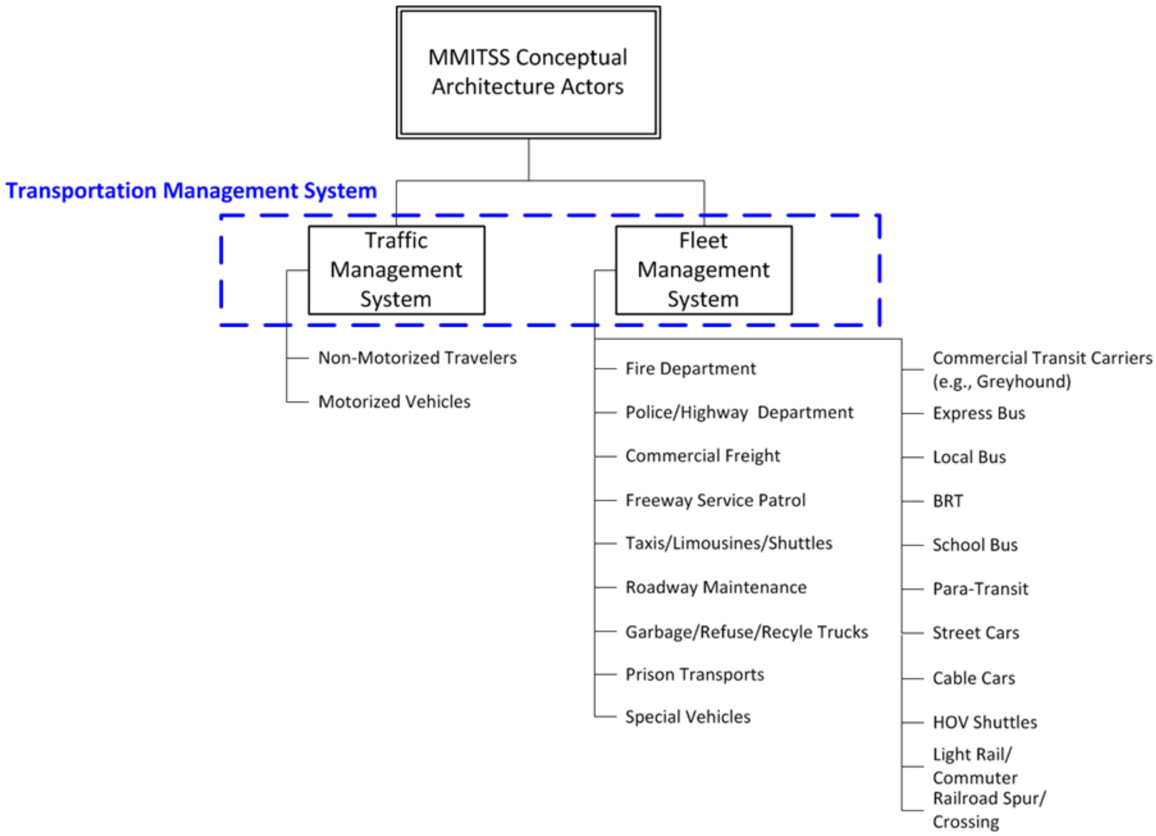

Figure 3 – MMITSS Transportation Management Actors

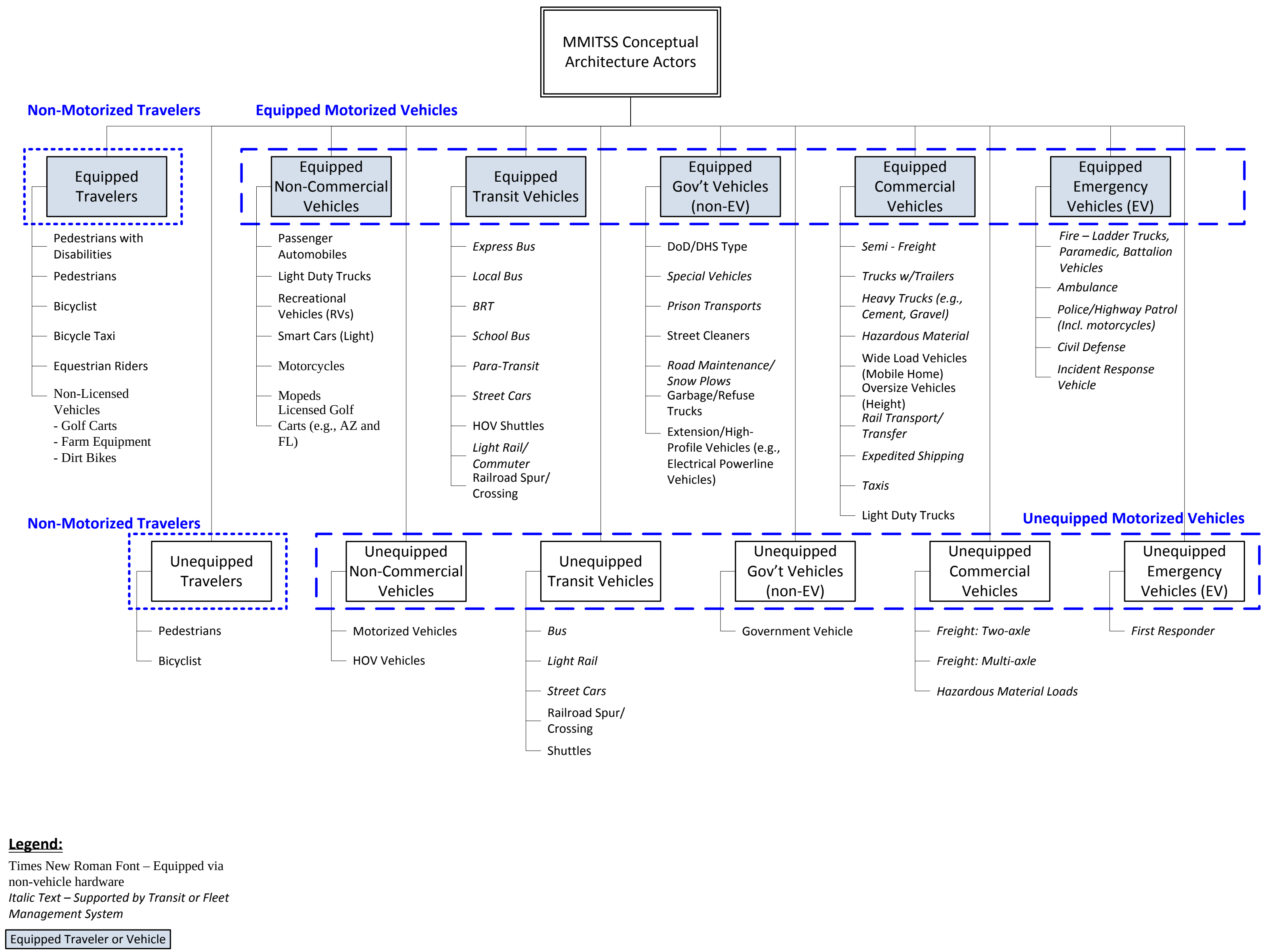

Figure 4 – MMITSS Equipped and Unequipped Actors

System Component (Node)	Transportation Mode				
	Vehicles	Transit	Pedestrians	Freight	Emergency Vehicles
RSE	• Broadcast MAP & SPaT Messages • Receive and track BSM • Translate BSM into Vehicle Phase Requests • Collect Performance Measures	• Broadcast MAP & SPaT Messages • Receive and track BSM • Receive SRM • Manage/Prioritize Requests (SRM) • Collect Performance Measures	• Receive and track Alternative BSM (Pedestrian) • Manage/Prioritize Request (SRM) • Broadcast MAP & SPaT Messages • Receive SRM Request • Collect Performance Measures	• Broadcast MAP & SPaT Messages • Receive and track BSM • Receive SRM • Manage/Prioritize Requests (SRM) • Collect Performance Measures	• Broadcast MAP & SPaT Messages • Receive and track BSM • Receive SRM • Manage/Prioritize Requests (SRM) • Collect Performance Measures • Provide SSM to OBE
OBE	• Receive MAP & SPaT Messages • Send BSM • Alert Driver to SPaT Information • Collect Performance Measures • Receive Pedestrian Safety Warnings	• Receive MAP & SPaT Messages • Send BSM • Determine Eligibility for Priority • Send SRM • Monitor Status • Collect Performance Measures • Collect Safety Measures		• Receive MAP & SPaT Messages • Send BSM • Send SRM • Monitor Status • Determine Eligibility for Priority • Collect Performance Measures • Receive Pedestrian Safety Warnings	• Receive MAP & SPaT Messages • Send BSM • Send SRM • Monitor Status • Collect Performance Measures
Nomadic Device		• Receive vehicle arrival time information	• Send alternative-BSM • Send SRM • Monitor Pedestrian/Signal Status • Receive Crossing Status		• Receive Warning about Approaching EVs
Traffic Signal Controller	• Provide Phase Service (call) and Extension • Provide dilemma zone protection	• Provide Priority Timing (early green, green extension, phase rotation, phase skipping)	• Provide Pedestrian Interval (Walk, Flashing Don't Walk, Don't Walk)	• Provide Priority Timing	• Provide Priority (preemption) Timing
Traffic Management System	• Provide Coordination (section) • Provide Adaptive Coordination Parameters (cycle, split, offset)	• Provide Route Based Priority • Manage Eligibility of Vehicles to Receive Requested Priority		• Provide Route Based Priority (required route information) • Manage Eligibility of Vehicles to Receive Requested Priority	• Provide Route Based Priority (required route information)
Fleet Management System		• Determine eligibility for priority (lateness, occupancy, service type, etc.)		• Determine eligibility for priority (lateness, cargo type, etc.)	Dispatch
Environmental Sensor(s)	• Weather information used to select plan (e.g. snow, rain, ice, wind)	• Weather information used to select priority parameters (e.g. snow, rain, ice, wind)	• Weather information used to select pedestrian interval timing (e.g. snow, rain, ice, wind)	• Weather Information used to select plan (e.g. snow, rain, ice, wind)	• Weather Information used to select priority/preemption parameters (e.g. snow, rain, ice, wind)

Table 2 - Summary of Responsibilities of System Component

9 Operational Environment

The MMITSS operational environment consists of a data rich and spatially and temporally dynamic environment. Figure 5 illustrates a simple two-intersection section of a signalized transportation network with both unequipped and equipped travelers from different models. The operational environment is also constrained by the policies that govern the operation of systems that span multiple modes. In this section, the physical, technical environment, and policy and institutional environments are discussed in terms of their impact on the successful operation of MMITSS.

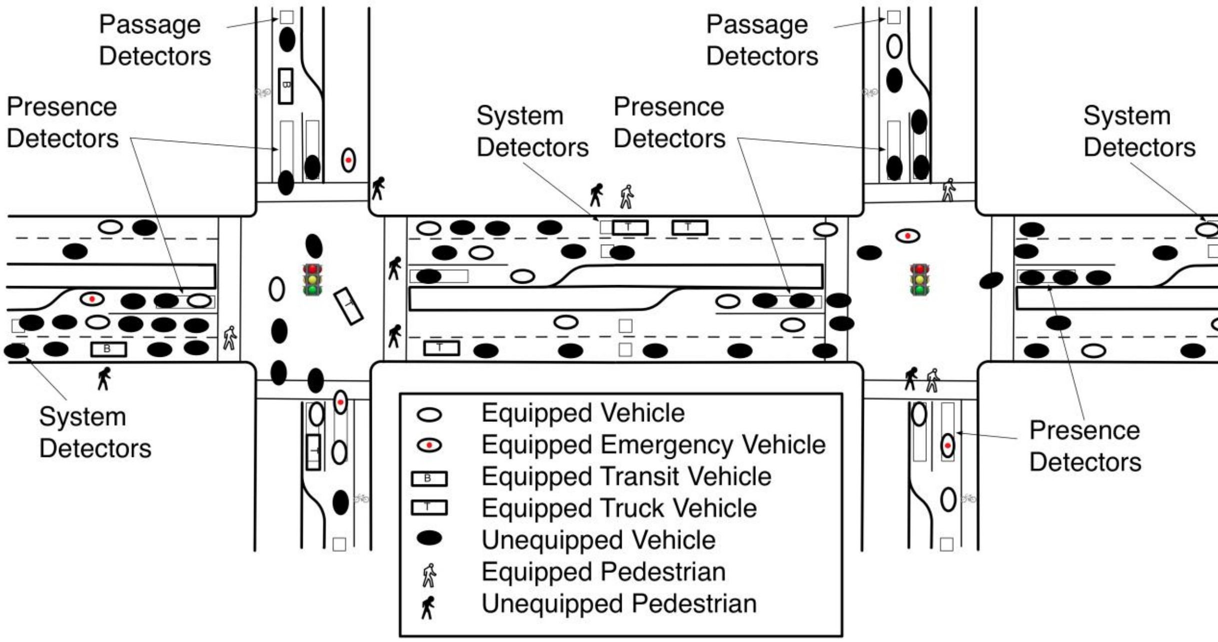

Figure 5 – Typical MMITSS Operational Environment

9.1 Operational Environment Assumptions

As with the development and integration of any transformational system, assumptions regarding the MMITSS operational environment must be established, stated, and monitored for compliance, consistency, and evolving technologies and policies. In this section, the main categories of assumptions are discussed in brevity, providing an introduction to assumptions and constraints discussed in detail within the MMITSS Requirements Document. The main categories of assumptions covered in this section are:

- MMITSS Integration Timeframe,
- Technology Insertion Point – Future versus Legacy Compatibility,
- Communication Resources,
- Interoperability,
- Effects and Impacts of Market Penetration,
- Geographical Scope and Boundaries, and
- Phased Levels of Interconnectivity with Transportation Management Systems.

The operational environment assumptions of the MMITSS system are governed by the overarching assumption of the MMITSS integration timeframe. As discussed during several Stakeholder meetings[5,6] a phased integration is assumed with early adoption by emergency vehicles and transit in a five year horizon followed by specific implementations of pedestrian and freight scenarios. Realistically, it will take 10 years before a full multi-modal system is deployed and operational. The primary limiting factor will likely be the adoption of connected vehicle technologies and nomadic devices by private passenger vehicles and pedestrians.

Although the MMITSS is a new and transformational system, it will be designed to interface with a *subset* of existing infrastructure and technology that spans an operational lifetime of over 50 years. As discussed with Stakeholders, Sponsors, and decision-makers, the MMITSS will have a well-defined technology insertion point enabling the development of system requirements and system design alternatives. At this point in time, the MMITSS development is proceeding under the assumption that the technology insertion point is identical to that specified in the Battelle project with respect to SPaT.[7] Again, the specificity of this assumption category will be detailed in the MMITSS Requirement Document.

As shown in the Conceptual Architecture Diagram in Figure 2, the operation and functionality of the MMITSS are highly dependent on the availability and timeliness of the supporting communications infrastructure, whether existing or planned. At this time, MMITSS assumes the availability of several forms of *wireless* communications including, DSRC (SAE J2735), Wi-Fi, Bluetooth, and 3G/4G. Regardless of the maturity levels of these communication standards and protocols, evolving capabilities within newer roadside equipment (RSE), onboard equipment (OBE), and traffic signal controllers (TSC) are highly possible. As such, the MMITSS development will rely on existing offerings while monitoring capability rollout in related efforts.

The details surrounding MMITSS interoperability is significant enough to warrant a separate chapter or section in the future MMITSS system requirement documents. Although an over simplification, the issue of MMITSS interoperability is concerned with the configuration of a system-of-systems with regards to the five overlapping modes: ISIG, transit, pedestrian, freight, and emergency vehicle. Each mode can be viewed as a separate, operational system, since it is theoretically possible to operate in the absence of the other modes. By virtue of its very nature and name, the Multi-Modal Intelligent Traffic Signal System is centered about interoperability of the diverse modes – operating together, collaborating, setting boundaries, and making tradeoffs with the intent to balance the operations of the distinct modes for overall enhanced performance. The associated assumptions with MMITSS interoperability are similar to the categories presented at the beginning of this section; (1) phased-in development, integration, and test will be implemented in contrast to the “Big Bang” approach to systems development; (2) technology insertion compatibility of the various modes is addressed in a phased-in offering; (3) communications compatibility may include a phased-in approach when TMS interoperability is considered; and (4) different market penetration rates for each of the different modes will affect the time progression and path of attainment of a fully multimodal system.

There are several facets to the concept of market penetration as it pertains to the MMITSS project. The most frequently discussed facets at recent Stakeholder meetings are associated with connected vehicles and nomadic devices, which may have various forms such as authorized, registered, and unregistered. There are shared assumptions with these two specific cases of market penetration: (1) expected rates of market penetration over the MMITSS development timeframe, (2) geographical market penetration with respect to urban versus rural areas, and (3) time dependent function of market penetration rates and

[5] MMITSS ConOps Workshop held on 7/18/12 in Washington, DC, PFS_ConOpsMeeting_071812,docx, p27.
[6] MMITSS Quarterly Meeting Minutes, 9/11/12, PFS_QuarterlyMeeeting_091112.docx, p2.
[7] MMITSS ConOps Workshop held on 7/18/12 in Washington, DC, PFS_ConOpsMeeting_071812,dox, p14.

feature capabilities or offerings. This latter assumption is significant. That is, while the market penetration is growing for either CV or nomadic devices, the supported features create a heterogeneous mixture of devices and capabilities. The obvious analogies in consumer electronics are PCs, operating systems, and smart phones. In the case of smart phones, it seems as though the application (app) features grow exponentially with new hardware offerings or revisions. It is reasonable to assume the MMITSS will encounter similar experiences over a five, ten, and twenty year perspective.

An example of a less obvious facet of market penetration has to do with urban versus rural disparities. Although specific programs are in place to provide technological advancements throughout the country, there are rural areas without ready access to even the Internet. The corresponding assumption is that there is a minimum level of market penetration required to make an MMITSS integration viable, without consideration of other mitigating circumstances such as security, safety, and extreme weather conditions.

The geographical scope and bounds of the MMITSS development require the specification of assumptions within the system requirements. ISIG provides the easiest example of geographical scope. As specified in the first and subsequent Stakeholder meeting, ISIG is organized as a hierarchical structure starting at an intersection at the lowest level, a section or sections at the middle level, and an overall system at the highest level. The geographical scope of each of these levels is easy to visualize and specify: (1) a single intersection and its interfaces, (2) a collection of adjacent intersections and their interfaces, and (3) a collection of intersections, transit operators, freight operators, transit management systems, fleet management systems, and the associated interfaces. This is an intuitive example of the boundary assumptions of the MMITSS. Within the MMITSS requirements document, less intuitive system boundary assumptions will be detailed, such as the physical and data interfaces of the supporting Fleet Management Systems.

The goal of this section was to highlight the categories of assumptions in the MMITSS operational environment. However, the assumptions associated with the physical boundaries of the MMITSS system are covered in subsequent sections on policy, safety, information assurance, data archiving, and institutional issues.

9.2 Operational Environment Description

The signalized transportation network composes much of the national transportation system. Figure 5 illustrates a sample network of two intersections with combinations of equipped and unequipped vehicles, including transit, trucks, emergency vehicles, and pedestrians. This figure is only intended to illustrate the environment and not to limit the scope to two intersections. Clearly, a traffic system consists of many sections or groups of intersections that work together to manage traffic. The existing traffic signal control system is based on controllers physically located at each intersection that receive information about vehicles and pedestrians from detectors (e.g., loop and pedestrian push buttons) and make decisions on control based on parameters (plans) that are configured by traffic engineers based on the time of day or prevailing traffic conditions. As vehicles and pedestrians adopt new technology they will become equipped travelers providing rich new data sets for decision making by the traffic control systems.

The key components of the new systems are the infrastructure-based roadside equipment (RSE) and the mobile equipment (OBE and nomadic devices). Applications will reside on both the infrastructure and the mobile equipment. The mobile applications will collect, process, and transmit data about the traveler and the traveler’s goals, as well as provide the user interface for travelers to input and receive information. The infrastructure applications will receive information from mobile applications and will make enhanced traffic control decisions.

This data will be communicated to the traffic signal system (MMITSS) using a variety of wireless communications technologies including DSRC (5.9 GHz), wifi (2.4 and 5.8 GHz), Bluetooth, 3G/4G, and possibly other emerging wireless communications media. Each of these media has strengths and weaknesses, including DSRC with rapid message transmission capability, low cost (Wi-Fi), extended range (3G/4G), etc. It is likely that a combination of these media will be used in the future.

The penetration rate of wireless communication and application adoption is likely to occur at different rates for each of the different modes. One possible scenario is that emergency vehicles and transit will be early first adopters. Priority for transit and preemption for emergency vehicles are common practices today that will benefit from new information and new cooperative control strategies. Agencies that adopt these technologies are likely to partner with commercial entities to equip freight vehicles with communications and applications so they can be part of the connected vehicle environment. Pedestrians with smartphones will likely adopt applications that are viewed as cool and beneficial. Pedestrians with disabilities are likely to accelerate adoption if the ease-of-use and benefits are substantiated.

It is likely that passenger vehicles will be slow to adopt the new technologies and the penetration rate could be low for many years. This will be accelerated if NHTSA decides to make this technology mandatory on all new vehicles, but that could take many years before the requirement is enforced and then many more before the fleet turns over. Of course, as with any transformational system and technology (e.g., smartphones) adoption could be faster if private vehicle owners perceive a substantial benefit.

9.3 Policy and Institutional Issues

9.3.1 Safety Considerations

There are other USDOT projects that are focusing on application of connected vehicle technologies to improve safety. As such, the PFS Panel has suggested that pursuing safety-specific applications in the MMITSS project is outside the intended project scope, although MMITSS needs to remain ever conscious of the safety implications of the applications that are intended primarily to improve mobility. Instead, the MMITSS Team and Sponsors will coordinate with the connected vehicle safety project teams to ensure that the system architectures are compatible and that the MMITSS leverages the technological foundations developed in these other projects.

9.3.2 Data and Information Security

The data-rich environment associated with connected vehicles includes responsibility for data and information security. As supported in the use cases, transmission and processing of data and information are critical to harnessing the benefits promised by MMITSS. For clarity, data and information are distinguished by their current state of usability. Data is considered to be “raw” or unprocessed, which is unusable until it is transformed (e.g., calibrated, scaled, etc.). In contrast, information is considered to be in a usable form that does not require further processing, although it can be enhanced by further processing.

With these definitions in mind, the hierarchy of security is apparent. Information security is at a higher level than data security. Within each of these two categories there is a hierarchy of security. As an example, the outside temperature provided by a connected vehicle’s OBE requires less security than the identification of the CV (e.g., VIN or other vehicle identifier).

9.3.3 Data Archiving

The discussion on data archiving has been broached at both Stakeholder meetings and the Stakeholder response has included both ends of the spectrum: (1) Keep the data indefinitely and share the data openly in a common format; and (2) Data shouldn't require much archiving, if any, to operate efficiently. During the ConOps Workshop, members of the PFS stated that the MMITSS Project was a research project. As such, the data should be collected, formatted, archived, and shared in a manner consistent with pursuing research in the MMITSS arena. Until such time as this guidance is modified by the PFS Panel, the MMITSS Project will comply with this guidance. The ability to collect and archive data can be designed to be configurable by the operating agency in compliance with local data archiving policy.

9.3.4 Allocation of Signal Priority

As described in Section 5, MMITSS will provide a hierarchical level of priority that can facilitate regional policies and preferences for priority control. For example, an agency may decide that emergency vehicles are given priority levels one (1) through four (4), where one (1) is assumed to have higher priority than four (4). Fire vehicles may be assigned to a level two (2), ambulances a level three (3), and police a level four (4), but if there is a critical event that requires the police to respond as quickly as possible, such as a person with a weapon at a school or shopping center, they may be given a level one (1) priority. Similarly, transit may be assigned levels five (5) through nine (9) where the level of priority depends on the class of service (BRT, Express, or local) as well as other factors such as lateness and passenger occupancy.

The fleet management system and the vehicle have the opportunity for determining the priority level for the vehicle before it communicates the request for service to the traffic control system (MMITSS). Freight and pedestrians might be assigned lower levels of priority. It is assumed that rail and cable cars are provided the highest level of priority (or preemption) due to the special characteristics associated with their operation (track clearance, gates down, dwell, free-running etc.). [Note: this structure and definition is consistent with NTCIP 1211 – Object Definitions for Signal Control and Prioritization].

Although the information provided above is suitable for the development of a prototype or proof-of-concept system, the allocation of the ten-levels of signal priority remains at the discretion of the local governing agency in collaboration with transit and fleet management system personnel.

9.3.5 Location of Priority Control

There are two distinct elements in the MMITSS concept of priority: (1) the level of priority, and (2) the methodology for granting the priority. The previous section reviewed the involvement of local agencies in the allocation of signal priority levels. In this section, the responsibility of priority decisions is discussed.

A vehicle requesting signal priority will communicate a priority message directly to the RSE. This message includes the request and priority level consistent with the allocation established by the local agencies. The RSE provides the request and priority level to MMITSS.

In the decision to grant priority, MMITSS incorporates the request message, prevailing traffic conditions, signal status, and the number and levels of priority requests from potentially multi-modal travelers. The location of priority decisions occurs at one of two levels: 1) Using a centralized approach, MMITSS decides the coordinated priority strategy for a section of signals or a network, and 2) Using an intersection approach, MMITSS decides priority control based on localized traffic signal performance (i.e., a particular vehicle will need to arrive at the intersection during a specified green window) while considering other requests for priority at the intersection.

9.3.6 Authorized Nomadic Devices

As described in Section **Error! Reference source not found.**, the MMITSS offers provisions for pedestrians with disabilities when equipped with an Authorized Nomadic Device. Since an Authorized Nomadic Device will enable pedestrians to request crossing priority, additional crossing time, accommodations during inclement weather, and perhaps safety indicators within connected vehicles, it is important that these specific devices are reserved for qualified users rather than pedestrians trying to game the system or gain an unintended advantage with the devices. As such, the MMITSS recognizes that there will be a credentialing process for authorizing and associating a nomadic device to a person with disabilities. This is analogous to acquiring a parking permit or placard for persons with disabilities. The process for authorizing or distributing this credential will reside with local agencies. However, the MMITSS must make provisions and accommodations for recognizing the credential whether it is an authorizing certificate or authorizing indicator within the supporting application software (aka: the app).

10 Support Environment

Complex systems, such as traffic control systems and MMITSS, require well defined systems for testing, validation, configuration, maintenance and repairs, and management assessment. These functions help the operating staff and agency provide a high quality system and assess the ability of the system to meet the goals that were established when the system was procured and deployed. It is assumed that the connected vehicle system will include tools for configuration and maintenance of the underlying subsystems including DSRC communications, backhaul communications, clock synchronization (for the RSE and OBE devices – probably using the GPS receivers), and backup of basic configuration data. MMITSS will be responsible for support and maintenance of all traffic control related functions.

Existing traffic signal controllers have status screens that allow traffic signal engineers and technicians to observe the timing of the phases and pedestrians intervals, calls received from detectors, gap and maximum timers, clock value, coordinator status, preemption/priority status, and communications status. These status screens on the controller are useful when reviewing programming and diagnosing problems. MMITSS introduces additional complexity through the MAP, which introduces geometric data into the traffic control problem, alternative sources of phase and pedestrian calls and extensions, multiple priority requests from multiple modes of vehicles as well as all of the inputs received from sensors/detectors. It is important for MMITSS to offer support tools that allow traffic engineers and technicians to observe and understand system behavior, especially when there are possible technical problems.

Tools to support MMITSS could include a geometrically correct, graphical representation of each intersection with real-time data overlaying the basic MAP information. Status of each equipped traveler could be highlighted and data from sensors/detectors could be illustrated. Such a tool would allow support users to observe and understand MMITSS operation. Since observers won't know which travelers are equipped and which are not, it is important to show the state of control decisions (e.g., decision to terminate or extend a phase) based on the location of equipped entities. Additional data about the status of MMITSS software components can be integrated into the display so support users can know that the software components are operating and processing data.

To support management assessment of MMITSS operation and performance, summary status data will be made available to traffic management systems to provide monitoring and oversight of MMITSS status (e.g., on-line, off-line, off). This data would be in addition to traditional information about signals running free, coordinated, preemption active, in flash, or when a communication failure occurs. Performance data collected by the infrastructure components (RSE) and vehicles (OBE's – communicated to the RSE) can be collected at defined intervals (e.g., once per minute) and displayed in the traffic management system.

These support tools are necessary for MMITSS adoption and deployment, but they are also critical to the research and development phase of MMITSS. These tools will support verification and validation of MMITSS operations during the test and evaluation phase as well as during integration testing.

In the following subsections, overview information is provided on the Arizona (AZ) and California (CA-PATH) testbeds that are planned for use in the critical stages of evaluating MMITSS design alternatives and during initial validation and verification (V&V) activities. The configuration of these systems supports the phased-in approach to system integration, test, and evaluation that was described in Section 9.

10.1 Arizona Testbed

Shown in Figure 6, the Arizona testbed is synonymous with the Maricopa County Department of Transportation (MCDOT) SMARTDrive Field Test Network. Located in the city of Anthem, Arizona (northern boundary of the Phoenix metropolitan area), this testbed consists of six intersections configured to support research, development, and demonstration of connected vehicle applications to improve safety and efficiency with an emphasis on control of traffic signal priority for transit and emergency vehicles.

Each of the intersections is equipped with Savari Streetwave RSE units, modern Econolite ASC/3 controllers, and a fiber optic Ethernet backbone. In addition, each of the intersections is configured with advance and stop bar detection on all movements. Although this area is not supported currently by regular transit service, the capability and functionality of transit vehicle priority has been demonstrated in previous tests.

For data collection and safety assessment purposes, the traffic patterns in this testbed are heavy in the morning and evening peak periods corresponding to commuter use. During mid-day periods, traffic patterns are compatible with equipment verification, testing, demonstration, and test data collection. The users of the Anthem network consist primarily of passenger vehicles, light commercial vehicles, pedestrians, bicycles, school buses and emergency vehicles (Daisy Mountain Fire). The average daily traffic counts (ADT) on Daisy Mountain and Gavilan Peak Parkway in 2010 was approximately 10,000 vehicles. Regular transit service is not currently available in the network. Past efforts for development and testing of priority control applications leverage strong relationships between Maricopa County DOT and the local agencies and neighborhood associations. Valley Metro provided a transit vehicle for demonstration testing. Daisy Mountain Fire Department and Maricopa County REACT vehicles have been used for emergency vehicle priority testing.

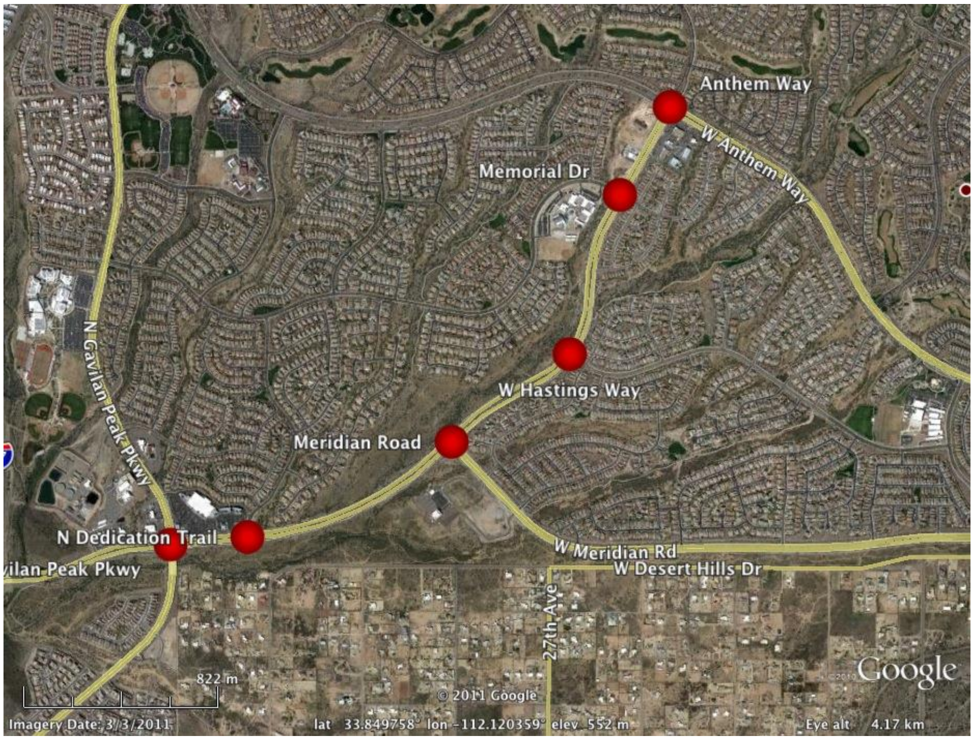

Figure 6 – MCDOT SMARTDrive Test Network

10.2 California Testbed

The California testbed is located along El Camino Real, a major arterial and state highway connecting South San Francisco to San Jose through the heart of Silicon Valley. This testbed is roughly two miles long and encompasses ten consecutive, signalized intersections within the city of Palo Alto. For this stretch of El Camino Real, Caltrans owns and operates all of the signalized intersections. By the scheduled time of MMITSS deployment and field testing, all ten signalized intersections will be equipped with 2070 Controllers, an open architecture controller providing standard interfaces such as RS-485 and Ethernet and a mixture of Savari and Arada 5.9 GHz DSRC RSEs. One of the intersections at California Avenue has a T1 backhaul connection and the other testbed intersections will have wireless backhaul connections.

For installation and maintenance during field testing operations, the research team needs the support of the local Caltrans traffic operations and maintenance crews. The research team plans to team up with local transit agencies, emergency vehicle operators, and freight companies to develop and execute the field tests using their vehicles. The light-duty vehicles will include some of PATH's experimental vehicles that have been instrumented with DSRC and data acquisition systems, as well as experimental vehicles owned by the automotive research laboratories that are located in the area.

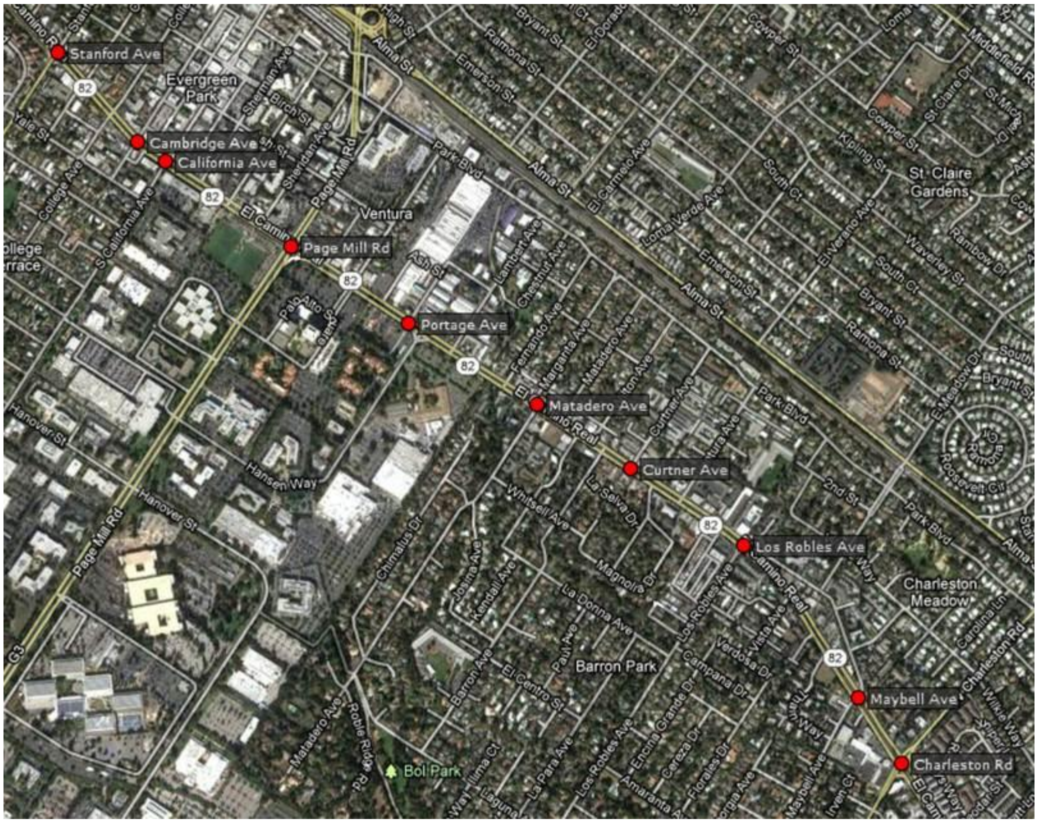

Figure 7 – El Camino Real Connected Vehicle Test Network

El Camino Real runs approximately north-south and has three lanes in each direction, plus one or two protected left turn lanes at each signalized intersection. It is parallel to two major freeways, I-280 to the west and US-101 to the east. There is also a commuter rail line that runs parallel to El Camino Real with a station located at California Avenue near the testbed section. Typical of major arterials, El Camino Real is busier during rush hour but maintains a significant amount of traffic during other hours of the day. The testbed section of this arterial is served by both regular and express transit buses that deploy Transit Signal Priority (TSP). Although this part of El Camino Real is not considered a heavily traveled truck route, many delivery trucks can be found in the area. At least one of the testbed intersections (California Street) is used heavily by pedestrians. Pedestrian push buttons are available throughout the testbed, which are useful in testing the MMITSS pedestrian use cases, especially when consideration of the arterial width is factored into the test cases. The California testbed will also include two signalized intersections in San Jose, where a light rail transit line operates in the median of a major arterial (North First Street). At these sites, the higher priority associated with light rail transit can be tested in complicated scenarios where left turning vehicles on the arterial need to cross the light rail tracks.

The California testbed will also include two signalized intersections in San Jose, where a light rail transit line operates in the median of a major arterial (North First Street). At these sites, the higher priority associated with light rail transit can be tested in complicated scenarios where left turning vehicles on the arterial need to cross the light rail tracks.

11 Operational Scenarios

The User needs are described in the form of operational scenarios for each of the modes and are written in non-technical, implementation-neutral vignettes. Then, the scenarios are mapped to the conceptual architecture via use cases contained in Section 13.3. Each use case describes a sequence of events or activities carried out by the user, the system, and the environment. It specifies what triggers the sequence, who or what performs each step, when communications occur and to whom or what [e.g., a log file], and what information is being communicated. The use cases must account for normal operating conditions, stress conditions, failure events, maintenance, anomalies, exceptions, and alternative operating methods. There are many ways to present scenarios and use cases. However, it is critical that the expected role or responsibility of each Stakeholder is clearly defined.

11.0 MMITSS Operational Scenario

This scenario represents the overall operation of the MMITSS as a system that integrates intelligent traffic signal control for multiple modes at the system, section, and intersection levels. The purpose of this scenario is to illustrate how the modal specific scenarios discussed in the following subsections (Sections 11.1-11.5) can be coordinated to achieve the goals of the MMITSS. For purposes of discussion, consider the system shown in Figure 8. Assume that the transportation management agency and metropolitan leadership have decided to divide the traffic signals into two network sections for the purpose of traffic management. Assume that Network Section 1 provides a network where there is a significant volume of trucks moving from manufacturing facilities to the interstate system. Network Section 1 also has a couple of transit routes that provide transportation to workers in the manufacturing facilities. Assume that Network Section 2 provides a network where there is significant commuter traffic that includes several transit routes and pedestrians. This network section serves morning and evening commuters, plus daily travelers going to and from school, shopping, and other activities.

Both sections are protected by emergency services that include fire, ambulances, and police. The transportation management agency has established a priority policy whereby all emergency vehicles have a higher level of priority than transit and trucks, but the relationship between transit and trucks may depend on the characteristics of the local network section. Within the emergency services the default level of priority is determined to be fire first, then ambulances, followed by police, but it is recognized that there may be situations in which the police will require the highest level of priority. This decision can be made based on the dispatch codes used by the local 911 service. It is assumed that the 911 dispatch system will provide an interface to the MMITSS priority policy subsystem where this can be dynamically assigned. Otherwise, the default priority levels are used when making these decisions.

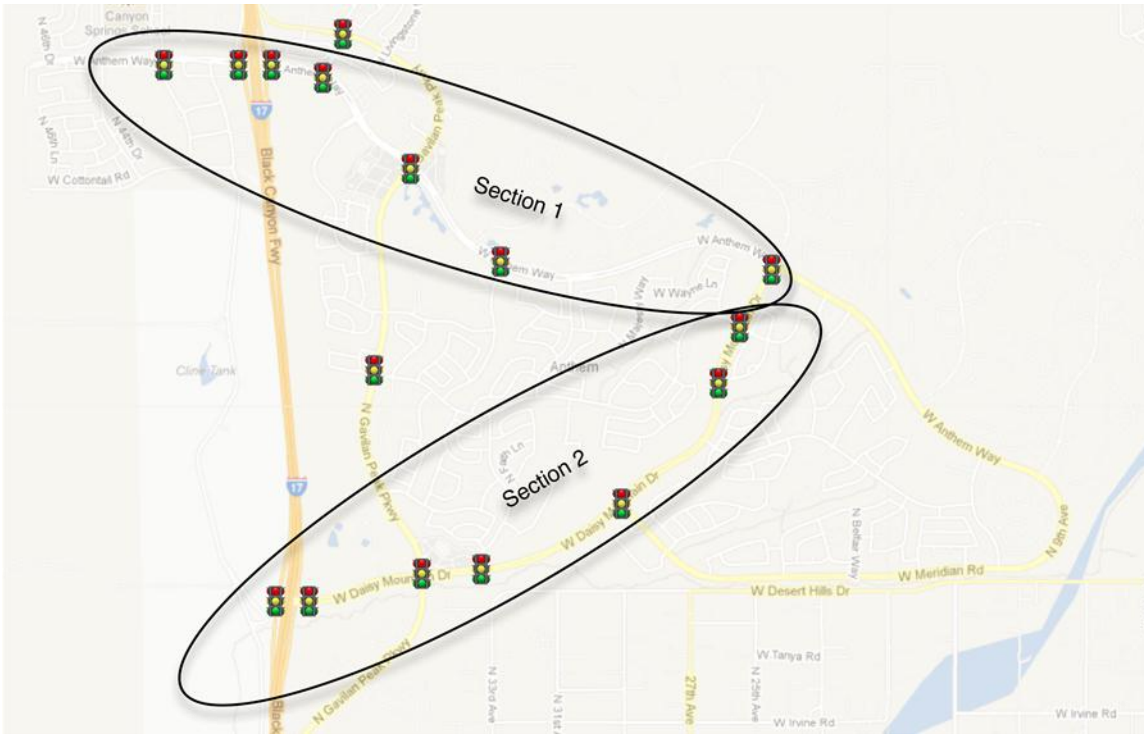

Figure 8 – A MMITSS System Organized into Two Network Sections for Traffic Management

11.0.1 Network Section 1

To best accommodate the goods movement in this section, the transportation management agency has worked with the local industrial representatives to establish a policy whereby Network Section 1 is operated in a coordinated system with a long cycle length to accommodate the heavy flow of trucks and trucks in this section will receive priority treatment when needed. Transit vehicles will receive priority, but their priority level will be lower that trucks. There is a concern about the potential for side-street delay for other vehicles. As such, the system will closely monitor the delay performance of the side street movements. Extra coordinated split times for the side streets can provide sufficient capacity for those movements since any unused split time will be reallocated to the main street coordinate phase when the side street has served all of the current demand. If the delay becomes excessive, the frequency of accepted priority requests can be reduced and the coordination parameters, phase splits and offset, can be dynamically adjusted.

There are a couple of transit routes in this network section that provide service for workers at the manufacturing facilities. The transportation management agency has worked with the local industrial representatives to agree that the trucks will receive a higher level of priority since the movement of the goods is their ultimate objective. In this scenario, all trucks have been determined to have the same level of priority, but trucks are determined to be more important than transit vehicles. Transit vehicles that are more than 3 minutes behind schedule during the morning and evening commute periods are allowed to request priority according to the agreed policy.

The MMITSS system will consider requests from multiple trucks and will attempt to provide priority service by stopping as few as possible and providing a progression green band for identified platoons of trucks (see Section 11.4.2).

There is some concern about the dilemma zone needs of trucks and other vehicles in the network due to the longer cycle length. The transportation management agency realizes that most of the trucks traveling in this part of the system will be equipped. Hence they can receive advanced dilemma zone protection (see Section 11.1.4). The dilemma zone protection will also provide intelligent phase termination (gap out – see Section 11.1.2and 11.1.3) since equipped trucks can be tracked as they approach this intersection. Similar service can be provided to the transit vehicles. Other vehicles may or may not be equipped. The network should have good vehicle detection (loop, video, radar, etc.) on the side streets, but there isn't the need for new or additional detection on the main street since the coordinated operation will return signal phasing to the main street frequently. Equipped vehicles will benefit from intelligent phase termination (gap out) and dilemma zone protection. Unequipped vehicles could receive dilemma zone warnings using roadside flashers if it is observed that this is an operational issue. The system will closely monitor the frequency of gap out and dilemma zone protection events. High frequency may suggest the coordination parameters, phase splits and offsets need to be adjusted.

There is not a significant volume of pedestrians in this network section so the pedestrian service is operated using pedestrian push buttons, or detection, for crossing the main street. Pedestrian service is on recall for crossing the side streets since the cycle time is long and the main street will receive most of the split time. Pedestrians that are using nomadic devices can request the pedestrian intervals using their devices and those that are disabled can receive extra crossing time if they are properly certified.

In the event of an emergency in the network section, emergency vehicles will receive the highest priority consideration and will override trucks and transit vehicles. When the number of trucks in the network is significant, route based emergency vehicle priority will be provided to assist in clearance of trucks, and other vehicles, from the emergency vehicles path. Since the route of the emergency vehicle may not be known, the route assumptions may extend only one or two signals downstream, but this will help reduce queueing in the emergency vehicle's path. Multiple emergency vehicles will be considered by reducing the total delay to all active emergency vehicles at an intersection. Each intersection will recover from emergency vehicle priority by considering the maximum delay of any single vehicle at the intersection.

MMITSS accommodates the collection of a variety of data and information for monitoring and assessing performance. A couple of sets of traditional system detectors could be located along the main street. These detectors will provide volume information so that the market penetration of equipped vehicles can be assessed. Performance measures related to the side street delay, the main street truck, transit, and vehicle delay, as well as throughput and travel time could be monitored. Additional measures, including the number of times equipped vehicles are in the dilemma zone when the service phase maxes out, arrivals on yellow and red, and pedestrian delay will allow the transportation management agency to monitor and assess performance. These performance measures will support the agencies reporting back to the local industrial community on the benefits they are receiving from MMITSS.

11.0.2 Network Section 2

To provide a high quality of service, the transportation management agency has established a policy whereby Network Section 2 is a pedestrian and transit friendly network, but they are aware of the volume of commuter vehicles in the mornings and the evenings. In addition to regular transit service (schedule based) there is a large volume of school buses that ferry children to and from school each morning and afternoon.

Since there may be multiple transit vehicles in the network section at any time, the transportation management agency has established a policy of reducing the total delay to the collection of transit vehicles at any intersection. The transportation management agency has established a policy for Network Section 2 where transit receives higher priority than other vehicles and pedestrians are provided priority when not conflicting with higher priority demands. Within the class of transit vehicles, school buses are determined to have the highest level of priority (e.g., at 4 on a scale of 1-10 where railroad crossings are assigned a 1, emergency vehicles are assigned 2 to 3, and transit vehicles are assigned levels 4-6) with trucks next. Transit vehicles are required to determine their eligibility for priority based on their schedule lateness. It is established that transit vehicles that are more than 3 minutes behind schedule (20% late assuming a 15 minute scheduled headway) can receive priority (e.g., a request at a level of 6). Transit vehicles that are more than 50% full of passengers are allowed to request a higher level of priority than just late vehicles (e.g., a request at a level of 5). Due to random boarding and alighting times, it is difficult to provide route based priority for transit vehicles, but downstream signals can be "priority aware" of vehicles that may be one or two cycles away and prepare by serving non-priority phases to ensure vehicles that are waiting receive minimal delay.

Since this network is determined to be transit and pedestrian friendly, the signals are coordinated, but at a relatively short cycle length based primarily on vehicle volumes and pedestrian crossing times. A time-of-day plan based control strategy is used to provide different cycle lengths depending on the different mix of the different modes of travelers. Longer cycle times may be required before and after school due to the volume of pedestrians near the school and school bus stops. Shorter cycles may by feasible during off peak times when passenger vehicles are the predominant mode. The morning and evening commuter traffic may cause congestion and require special consideration and require limiting the level of priority control for transit while oversaturated conditions are managed (see Section 11.1.3).

In the off-peak operational periods, or during lower volume periods, the signals may operate in free mode (non-coordinated) with intelligent phase actuation (phase call and gap out logic – see Sections 11.1-11.3). This will provide a high quality of service to the vehicles that are present in the network. The Network Section and individual signals may self-determine when to coordinate and when to operate in a free mode based on the observed vehicle tracks at the approach to the intersections and performance measures compiled by MMITSS. If the signals are operating in a free mode and there is a significant volume of vehicles arriving randomly over time (at an interior signal), then it may be beneficial to change to a coordinated plan and platoon vehicles so they can progress together through the network. Similarly, if the signals are operating in a coordinated plan and there are very few vehicles arriving during the coordinated phase green time, it may be beneficial to drop to a free mode.

Special events are likely in a network section where there are schools – e.g. sporting events, plays, etc. Extra transit service may be provided for these events and traffic volumes may vary significantly. Special transit vehicles may be provided a high level of priority (e.g. 5 of 10). Vehicle volumes may result in long queues that could block intersections and short-term congestion may occur. MMITSS will provide special congestion control considerations (see Section 11.1.3).

In the event of an emergency in the network section, emergency vehicles will receive the highest priority consideration and will override trucks and transit vehicles. When the number of transit vehicles and pedestrians in the network is significant, route based emergency vehicle priority will be provided to assist in the clearance of pedestrians (e.g., long clearance times). Since the route of the emergency vehicle may not be known, the route assumptions may extend only one or two signals downstream, but this will help reduce queueing in the emergency vehicles path. Multiple emergency vehicles will be considered by reducing the total delay to all active emergency vehicles at an intersection. Each intersection will recover from emergency vehicle priority by considering the maximum delay of any single vehicle at the intersection.

Performance measures will be continuously collected to characterize the operational effectiveness of the signals in Network Section 2. The goals of being transit and pedestrian friendly will be supported by measures that include transit vehicle delay for those vehicles that request priority (e.g. late vehicles) and pedestrian delay (time from when the pedestrian requests service – either by pedestrian detection or nomadic device).

11.1 Intelligent Traffic Signal System Scenarios

Intelligent Traffic Signal System (or ISIG) provides the underlying functionality of the MMITSS operations by virtue of its control and connectivity with the traffic signal control. Within the MMITSS ConOps, the ISIG modality is developed into four classes of scenarios: Basic Signal Actuation, Coordinated Section of Signals, Congestion Control, and Dilemma Zone Protection. Utilization and performance measures can be used to adjust/adapt signal timing to improve operations and are collected and updated as part of the use cases defined for equipped vehicle scenarios and presented in Section 13.3.1.

11.1.1 Basic Signal Actuation

Three scenarios are used to develop the operations of basic signal actuation: Single Unequipped Vehicle Signal Actuation, Single Equipped Vehicle Signal Actuation, and Multiple Vehicle Actuation. The latter scenario makes use of the prior scenarios to support the accommodation of multiple vehicles of unequipped, equipped, or mixed configuration. These scenarios are developed in the following subsections and links are provided to the related use cases and Stakeholder feedback for traceability.

11.1.1.1 Single Unequipped Vehicle Signal Actuation

Consider an unequipped vehicle approaching an intersection. This scenario is relevant to legacy vehicles, non-operational OBEs, or unavailable RSEs. Assume the design speed for the roadway is 35 mph (51.3 fps). When the vehicle is 250 feet from the intersection and the signal is green, the vehicle crosses an extension detector and resets the gap timer to 5.0 seconds. When the vehicle leaves the detector the gap timer starts counting down. As the vehicle reaches the stop bar, the timer reaches 0.0 seconds and the phase gaps out to the yellow interval.

The active nodes for this scenario are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 9. The corresponding use case for this scenario can be found in Section 13.3.1.

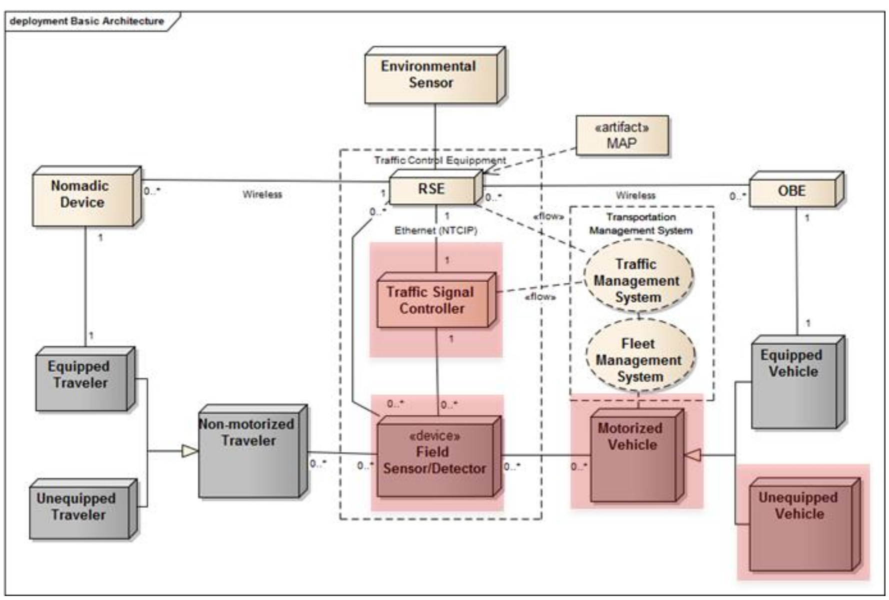

Figure 9 – Active Architecture Nodes for Unequipped Signal Actuation

11.1.1.2 *Single Equipped Vehicle Signal Actuation*

Consider another vehicle on a similar trajectory, but this vehicle is equipped and only traveling 25 mph (36.7 fps). When this vehicle reaches the communications range (e.g., DSRC at approximately 300 m or 984 ft) the RSE begins to receive Basic Safety Messages (BSM) from the vehicle. The RSE calls the desired service phase, but the signal continues to serve other phases that have active calls. As the vehicle reaches the extension detector, the RSE notes that the detection event was generated by an equipped vehicle and instead of resetting the gap timer, it places a hold on the phase that has recently changed to green. The hold is maintained until the vehicle crosses the stop bar 6.8 seconds later (notice that this is 1.8 seconds after the signal would have gapped out under normal extension operations). Comparing the scenarios of the equipped and unequipped vehicles, the connected vehicle would have been served by the green whereas an unequipped vehicle would have been stopped – or could have entered the intersection during the clearance interval. This scenario is relevant to connected vehicles configured by OEMs or retrofitted with compatible OBE.

The active nodes for the single, equipped vehicle signal actuation scenario are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 10. The use case for this scenario can be found Section 13.3.1.

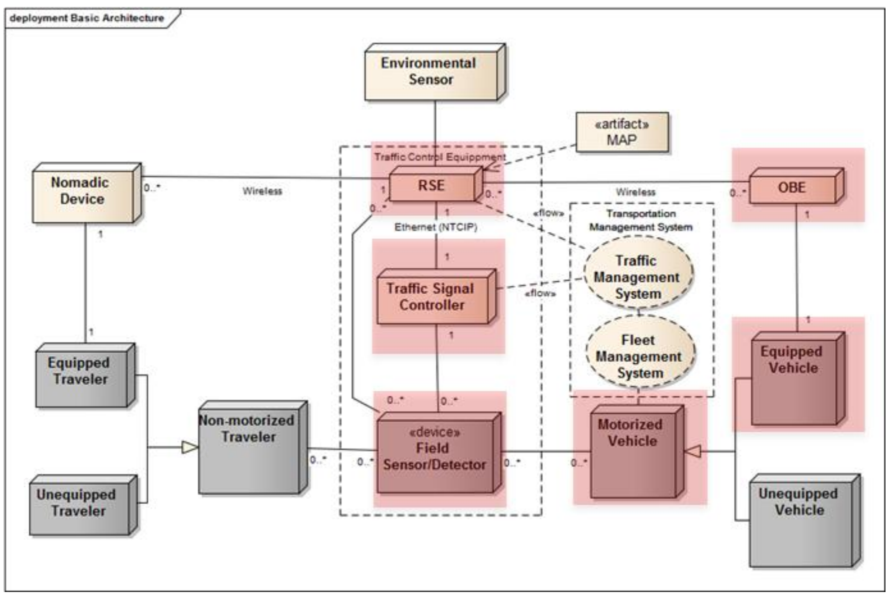

Figure 10 – Active Architecture Nodes for Single Equipped Vehicle Signal Actuation

11.1.1.3 *Multiple Vehicle Actuation*

Consider several equipped vehicles approaching an intersection from conflicting directions. This scenario includes the Single Signal Actuation scenarios discussed previously with the added understanding that each equipped vehicle, or unequipped vehicle, will call the signal control phases so that they are served in the order as determined by the programming of the traffic signal controller. The equipped vehicles are treated in a similar fashion, except that the controller logic will assess the likelihood that a vehicle will arrive at the stop bar before the phase will terminate due to the phase max out time or a coordinator force off point. If the vehicle will not arrive in time, then the signal should be allowed to terminate early (efficiency).

The active nodes for the multiple, equipped vehicle signal actuation scenario are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 11. The use case for this scenario can be found Section 13.3.1 and offers provisions for collecting and updating performance measures for continuous performance improvement.

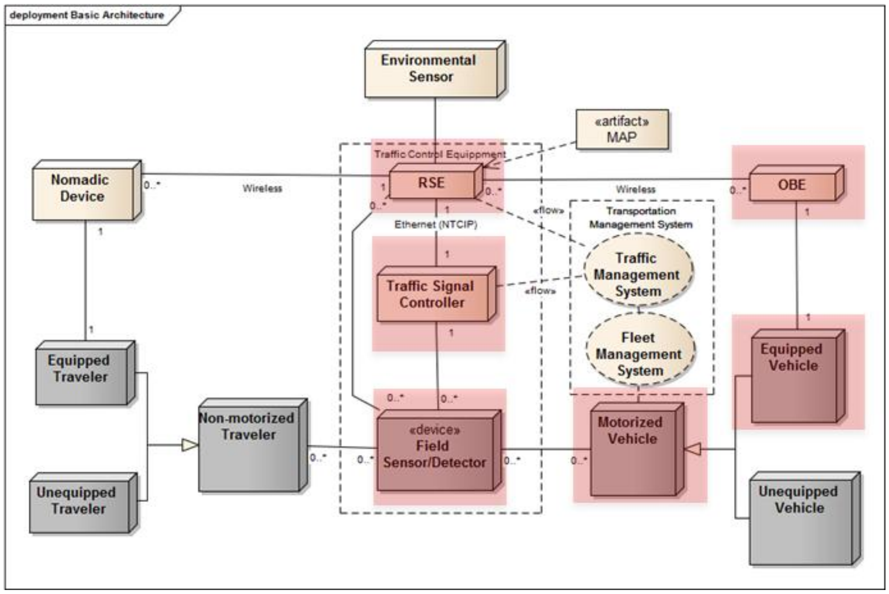

Figure 11 – Active Architecture Nodes for Multiple Equipped Vehicle Signal Actuation

11.1.1.4 Ramp Metering Signal Actuation

The Stakeholder comments supporting the inclusion of Ramp Metering Signal Actuation in the MMITSS Project were supported in both the Stakeholder Meeting and ConOps Workshop. It was suggested that ramp metering spillback and ramp metering priority be considered at least as a future or phased-in offering of a multi-modal system. Inclusion of this topic area would permit future accommodation of alternative routes for EVP and incident mitigation, which supports the Congestion Control scenarios.

11.1.2 Coordinated Section of Signals

Coordination is a technique used to provide green bands or progression bands for safe and efficient movement of a group (platoon) of vehicles through a section of traffic signals. For the purposes of this discussion, a platoon is defined as a group of vehicles traveling in the same direction with short and similar headways along the main street of the section. There may be a primary platoon and secondary platoons that result from groups of vehicles turning onto the main street, but coordination is concerned with the primary platoon. The platoon may slow or stop at the first signal in the section, but it is desired that it progress through the other signals in the section without delay or stops. Typically a coordinated section is 5-7 signals, but this depends on the geometry (signal spacing, etc.). As the platoon approaches the other signals in the section, it may slow due to a queue discharging or it may progress without delay. The offset between the signals in the direction of the progression band determines this behavior. A good offset will allow the platoon to progress without delay. A poor offset causes delay and stops. The size of the queue is random, but the time to clear it should be sufficient, but not too long, allowing minimal impact to the platoon.

Adjustment of coordination parameters, primarily the offset, can be made based on the performance measures related to platoon progression in the desired direction of the green band. Adjustment of cycle length and phase splits is generally related to phase failure (e.g., the failure to completely discharge a queue during a green service interval) or excessive phase time (which can result in early return to green for the coordinated phase and inefficient use of green time). Accurate estimation of these performance measures can be significantly improved using probe data from equipped vehicles. Vehicle trajectories allow accurate assessment of offset quality and true phase failure estimation.

The active nodes for the coordinated section scenario are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 12. The use case for this scenario can be found Section 13.3.1.

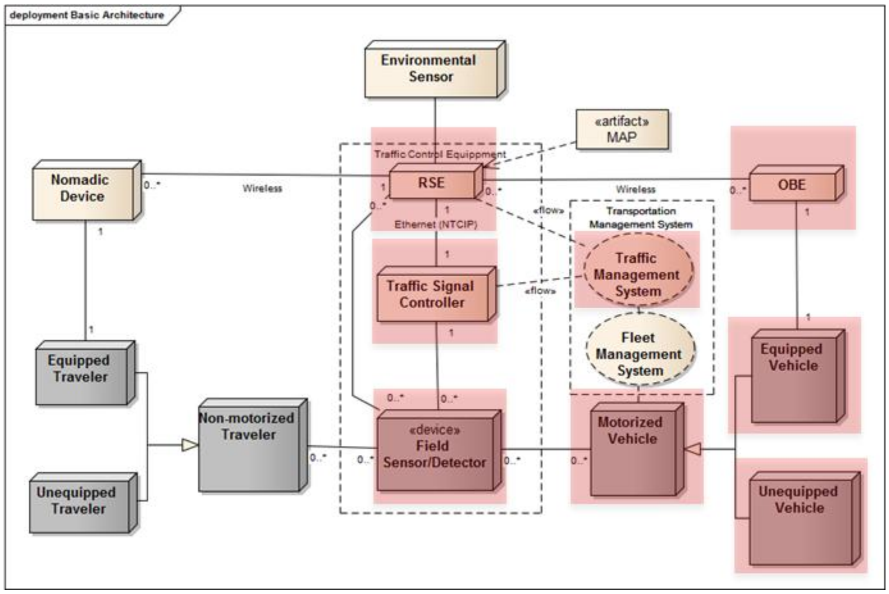

Figure 12 – Active Architecture Nodes for Coordinated Section Scenario

11.1.3 Congestion Control

From a technical perspective, congestion occurs when one or more approaches to a traffic signal fail to serve the demand over several cycles. Continued failure (called phase failure) over many cycles can cause queues to spillback to upstream intersections resulting in network wide congestion. Congestion can be characterized by the duration (amount of time that one or more intersections have persistent phase failures) and by the extent (distance in space where the intersections are congested). Traditional traffic control systems can estimate phase failures by considering stop bar detector occupancy at the beginning and end of the service phase (green), but these systems cannot distinguish between situations where newly arriving vehicles are stopped or when vehicles are stopped for two or more cycles. Connected vehicle data provides the opportunity to accurately estimate phase failures and the persistence of congested conditions.

From a Stakeholder or user perspective, congestion is perceived to exist when large groupings of vehicles sit idling through multiple signal cycles with little progress or relief. Then, this situation is repeated at an adjacent signalized intersection or several neighboring intersections. Users observe this occurrence during specific times of day, such as morning and evening rush-hour traffic, or during special events such as sporting events, holiday shopping, funeral processions, political motorcades, and scheduled or unscheduled roadway maintenance. Less frequent observations of occurrence accompany accidents, incidents, and inclement weather.

Regardless of the underlying cause of the congestion, the typical user is left wondering, in spite of all the technological advances available, why they are in traffic wasting their time and expensive fuel, harming the environment, and incurring wear-and-tear on their expensive automobile. From Stakeholder perspectives, the problem and frustration are extended to include increased emissions, decreased productivity, increased driving hazards, reduced availability during emergency responses, reduced access to businesses, and a decrease in customer satisfaction.

Strategies for managing congestion include: free operation, phase split adjustment, cycle length adjustment, and queue management. If a signal is in a coordinated section, it can drop from coordination and run in a free mode so that there is no coordination constraint. Split adjustment involves lengthening one or more phase splits while reducing other splits within a fixed cycle length.

Accessing and interacting with equipped vehicles offer both near-term and long-term improvements to congestion control. In the near-term while market penetration is increasing, equipped vehicles will provide initial estimates of the occurrence of congestion, root cause of congestion, rate of change of congestion, and information of route modification to avoid congestion if some form of vehicle identification is available for tracking. Initially, access to congestion data will enable traffic engineers to analyze flow more thoroughly. Initial integration of congestion data into phase adjustment, cycle length adjustment, and queue management will permit near real-time analysis and mitigation. After sufficient data is collected and analyzed, time-of-day or anticipatory control can be introduced to mitigate or delay the occurrence of congestion. The long-term perspective offers the possibility of integrating congestion control information into hand-held and vehicle navigation systems for the purpose of mitigating congestion with a multifaceted approach.

The active nodes for the congestion control scenario are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 13. The use case for this scenario can be found Section 13.3.1. The inclusion of specific steps to collect and update performance measures permits immediate MOEs and the basis for further analysis of the intersection, section, and network. As mentioned previously, an important consideration in a connected vehicle environment is the use of vehicle data (BSMs) for estimating queue and phase failures.

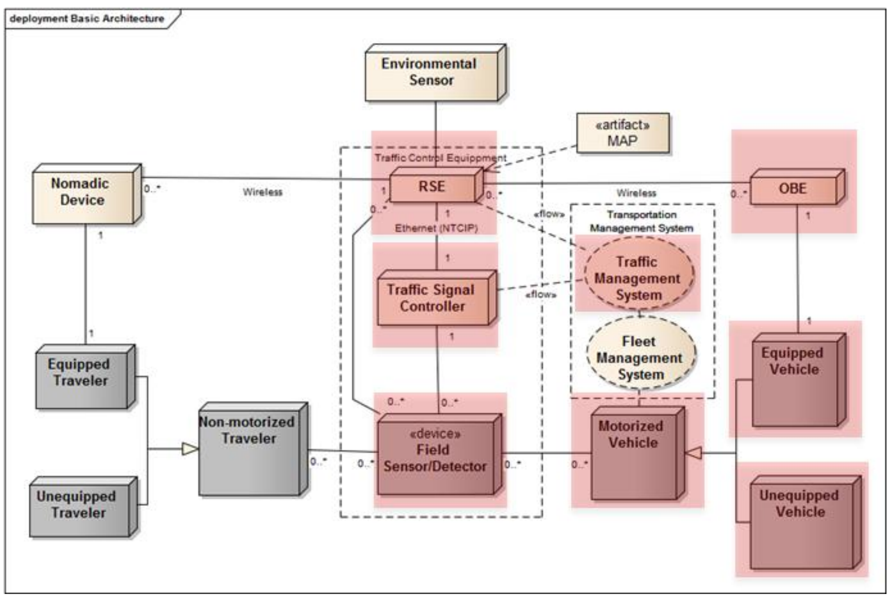

Figure 13 – Active Architecture Nodes for Congestion Control Scenario

11.1.4 Dilemma Zone Protection

A dilemma zone occurs when a vehicle on a high-speed approach cannot stop safely when the traffic signal changes from green to yellow. The occurrence of dilemma zones can be complicated when coupled with inclement weather, such as rain, sleet, ice, and snow, or when they involve heavy or large vehicles, such as loaded freight vehicles, tanker vehicles, and wide-loads. Yet, it is these cases that provide situations and scenarios to showcase the benefits of connected vehicle data. Recent approaches to dilemma zone control [Bonneson, ref] have utilized multiple (two) fixed location detectors to protect vehicles. The first detector starts an extension (gap) timer based on the travel time from the first detector location to the second detector location. If the vehicle arrives at the second detector before the extension timer reaches 0.0, then the second detector restarts the extension detector. The detector locations and extension timer values are designed so that the vehicle is allowed to cross the stop bar safely. If the vehicle is not traveling fast enough to reach the second detector before the extension timer reaches 0.0 then the vehicle should be able to stop in time. The exception to the process is when the phase reaches the maximum time and the phase is forced to terminate (advance to yellow) regardless of the status of the approaching vehicle(s). Advance warning flashers can be installed at a sufficient stopping distance upstream of the signal. These warning flashers start at a predefined interval before the signal reaches the maximum time (or termination point).

In a connected vehicle environment, the Basic Signal Actuation use cases (single and multiple vehicles) fundamentally manage the dilemma zone situation. However, the same condition exists when the phase reaches the maximum green time, except the controller can decide to terminate the phase early (rather than start the first extension timer) since it can track the approaching vehicle over a sufficiently long distance. If one or more equipped vehicles are approaching the signal and the controller has decided to extend the green interval for these vehicles and a new vehicle approaches that will not reach the stop bar before the start of the yellow interval, this new vehicle can be in the same dilemma zone situation. In addition, the equipped vehicle characteristics (type, length, weight, etc.) can be used to determine the safe stopping distance and evaluate the extension/termination decision. For example, a large truck could have more difficulty stopping than a small passenger vehicle. The infrastructure based warning flashers can be used to warn the vehicle and/or a warning message could be sent to the specific vehicle that is at risk.

The active nodes for the dilemma zone scenario are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 14. The use case for this scenario can be found Section 13.3.1.

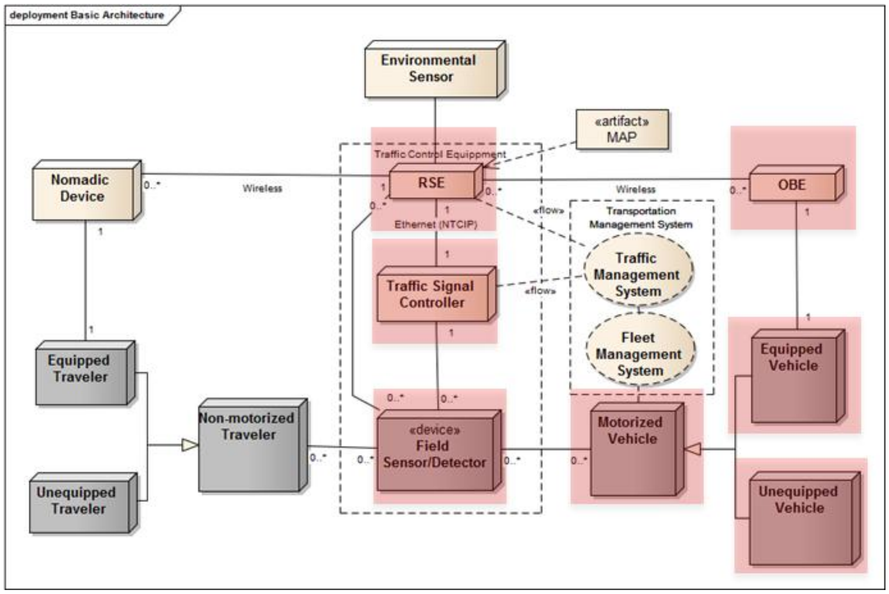

Figure 14 – Active Architecture Nodes for Dilemma Zone Scenario

11.2 TSP Operational Scenarios

There are a number of operational TSP scenarios that are discussed in this section. MMITSS offers new opportunities to improve the state of the art in TSP systems. Recent ITS and communication advances offer more accurate and richer information for TSP-based systems resulting in the potential for better performance and higher reliability. Equipped transit vehicles are capable of communicating vast amounts of data to the intersection through the RSE. This data includes information about a transit vehicles current position, speed, heading, and level of priority. When multiple transit vehicles approach a signalized intersection at approximately the same time, certain transit vehicles may have a higher consequence for stopping and larger benefit for proceeding unimpeded through TSP control, which is initiated by the communicated level of priority defined in the operational policy established by the decision making stakeholders (See Sections 9.3.4 and 9.3.5 for details).

This section presents three types of TSP operational scenarios developed for the MMITSS Concept of Operations, including (1) a basic scenario and variations for transit buses at a single intersection, (2) a rail scenario (TSP and preemption) for highway-rail crossings in urban areas, and (3) an extended scenario for multiple intersections. The use cases associated with these scenarios are presented in Section 13.3.2.

For all of the TSP operational scenarios, it should be noted that the communications of priority requests is made locally through OBE-to-RSE communication, but it could also be realized using alternative communications including centralized systems if traffic management system and transit management system are capable of communicating with each other to facilitate priority requests. This architecture is consistent with the NTCIP 1211 Concept of Operations.

The active nodes for the transit signal priority scenarios are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 15.

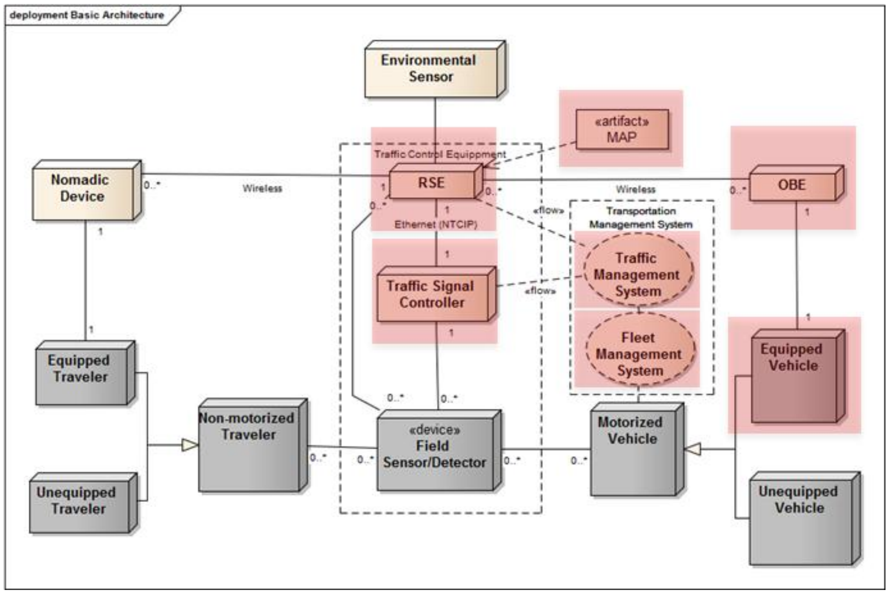

Figure 15 – Active Architecture Nodes for TSP Scenarios

11.2.1 Basic TSP Scenario and Variations

The basic TSP scenarios are based on the assumption that the transit vehicles communicate TSP requests with the immediate downstream intersection and the TSP decisions are granted locally by the intersection.

11.2.1.1 Basic TSP Scenario

The basic TSP scenario addresses transit vehicles approaching an equipped intersection. Each vehicle continuously monitors its schedule/headway adherence and passenger loads to determine whether there is a need to request signal priority. When conditions are met, the vehicle sends a priority request (SRM) to the roadside. The level of priority, assigned to the vehicle according to the established priority policy, will be included in the priority request. While approaching the intersection, the vehicle will periodically send location updated messages (i.e., BSMs) to the roadside until it clears the intersection.

The roadside equipment processes SRMs and BSMs sent from the transit vehicles and determines the most appropriate priority control strategy based on a number of factors, including the prevailing traffic condition and the requested level of priority. In urban areas, requests for priority may occur on conflicting approaches of an intersection. The priority timing routine shall have the intelligence to apply sophisticated strategies rather than “first called, first served” for conflicting requests. The roadside equipment will continue to monitor changes in signal status and transit vehicle location so that adjustments can be made as needed.

Two use cases associated with this scenario (single transit vehicle at one signalized intersection, and multiple transit vehicles at one signalized intersection) can be found in Section 13.3.2.

11.2.1.1.1 Transit Signal Priority at Nearside Bus Stops

Nearside bus stops (located right/near the stop bar) are challenging for TSP implementations due to the uncertainty of dwell time at the stop. As such, nearside stops are not typically suggested for TSP implementations. Transit vehicles often experience longer delays at intersections with a nearside stop. The transit vehicle has to wait in the traffic queue before it can reach the nearside stop to allow passenger loading and alighting, and has to wait for another signal cycle after finishing the passenger activities.

Under this scenario, the functions performed by the transit vehicle are essentially the same as those described in the previous basic TSP scenario, but accommodations are included in the sequence of events for the nearside stop. These accommodations are initiated by door open/close status in the priority request messages, as well as MAP information on the nearside stop. The roadside equipment manages the potential of a queue between the bus and the nearside stop. When the bus reaches the stop and the doors open, an updated request message (SRM) is sent to the intersection. While the bus dwells to allow passengers to board and alight, the signal controller may terminate the service phase to serve other vehicles and return service when the doors close.

MMITSS estimates the queue length on an approach to a nearside bus-stop using fused probe vehicle data and loop detector data, and predicts the expected arrival time at the back of the queue for the transit vehicle. Priority for the through movement is granted to clear the queue in front of the transit vehicle allowing quicker entrance to the nearside stop.

Once the transit vehicle reaches the nearside stop, priority will be granted only when the door is closed, indicating the transit vehicle has finished passenger loading/alighting and is ready to depart from the stop.

The use case for this scenario can be found in Section 13.3.2.

11.2.1.1.2 Transit Signal Priority for Left Turn with Protected Signal

This is an extension of the basic TSP scenario that addresses signal priority for transit vehicles making a left-turn with protected signal. The scenario applies to intersections that have either a short left-turn pocket or long queue for the through movement which blocks the access of the left-turning bus to the left-turn pocket.

The operation of this scenario is similar to the scenario of applying TSP at nearside bus-stops. When approaching the intersection, the vehicle communicates the need for and level of priority with the roadside equipment. MMITSS estimates the queue length in front of the bus and predicts the expected arrival time of the bus at the back of the queue. When the traffic queue is expected to block the access of the transit vehicle to the left-turn pocket, signal priority is granted in two stages: 1) granting priority for the through movement to clear the queue so that the transit vehicle can access the left-turn pocket sooner, and 2) granting priority for the left-turn movement to reduce delay of the transit vehicle.

Balancing multiple requests for priority with different levels of priority and making trade-offs between traffic and transit at the intersection is addressed by the selection of priority timing for the particular situations presented.

The use case for this scenario can be found in Section 13.3.2.

11.2.2 Operational Scenarios for Rail Crossings in Urban Areas

11.2.2.1 TSP Scenario for Rail Crossings

This scenario extends the basic use case from Section 11.2.1.1 to include interoperability with a crossing interconnect to address priority requests from transit rail vehicles at rail crossings in urban areas. For the purposes of this development, a rail crossing is characterized as a location having gates and warning lights that are used to secure a safe crossing for a rail based vehicle. The use case for this scenario can be found in Section 13.3.2.

11.2.2.2 Preemption Treatment for Transit Rail Vehicle

This is an extension of the baseline TSP control to address preemption control of Transit Rail Vehicles at rail crossings typically involving gates in urban areas. As with baseline TSP, it is assumes that the traffic signal controller has been configured to provide preemption functionality. However, this scenario assumes the inclusion of and interoperability with a rail crossing interconnect that activates preemption after receiving information from an approaching transit rail vehicle. The use case for this scenario can be found in Section 13.3.2.

11.2.3 Extended TSP Scenario

While signal priority can reduce delay effectively for transit vehicles at a given signalized intersection, many times the bus has to stop longer at the downstream intersection such that there is no net time saving for the transit vehicle while imposing an impact on non-transit traffic due to the TSP execution. The centralized TSP control considers priority requests from multiple buses and the coordination of TSP treatments among a sequence of signalized intersections to ensure each granted priority benefits transit vehicles.

This scenario requires the transit fleet management system (FSM) to assign the levels of priority for its routes and/or for particular transit vehicles, and communicate information about levels of priority and priority routes to the Traffic Management System (i.e., MMITSS).

When approaching an equipped intersection, the transit vehicle communicates a request for priority (SRM) that includes the appropriate level of priority to the roadside equipment. Then, the request is transmitted to the traffic management system for further processing. The traffic management system collects requests for priority from each connected intersection and associates the requests with levels of priority obtained from the fleet management system. The Traffic Management System forms sections of signals according to the characteristics of priority routes and multiple requests for priority. Then it determines the signal priority strategy for coordinating priority control of signals within a section (e.g., the expected green start and/or green end time for the priority movement at each individual intersection). The traffic management system communicates its decision to the individual intersection. At each intersection, the signal timing is optimized to meet the priority requirement while balancing the impact among all approaches to the intersection.

The use cases for these scenarios (single transit vehicle and multiple transit vehicles) can be found in Section 13.3.2.

11.3 Pedestrian Mobility Operational Scenarios

According to the MUTCD, the presence of a pedestrian is defined as a person being within six feet from the face of the curb or from the edge of the pavement at the beginning of the WALK signal indication and assumes a walking speed of 3 ft. per second to the far side of the street or to the median if a two-stage pedestrian crossing sequence is used. The total of the walk interval and pedestrian clearance time should be sufficient to allow a pedestrian to cross the intersection in the crosswalk.

Although this category is called “pedestrian mobility”, it applies to non-motorized travelers in general, including bicyclists. They are just as likely to be equipped with nomadic devices that can provide connectivity with the traffic control infrastructure, and have similar mobility needs. The major difference from pedestrians is their higher traveling speed, which means that they need less crossing time than pedestrians. Although, it should be noted that bicyclists are generally grouped with pedestrians, they are required to follow the same operating laws as motorized vehicles and often behave more like motorized vehicles than pedestrians. For example, bicyclists often use left turn lanes rather than crossing using the pedestrian crosswalks.

11.3.1 Unequipped Non-Motorized Traveler

The MMITSS must support manual pedestrian call sensors previously installed, operational, and planned in future infrastructure configurations. In these cases, the pedestrian crosswalk light is activated by traditional push button or by pedestrian detection sensors.

The active nodes for the Unequipped Non-Motorized Traveler scenario are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 16. The Unequipped Pedestrian Crosswalk Activation use case can be found in Section 13.3.3.

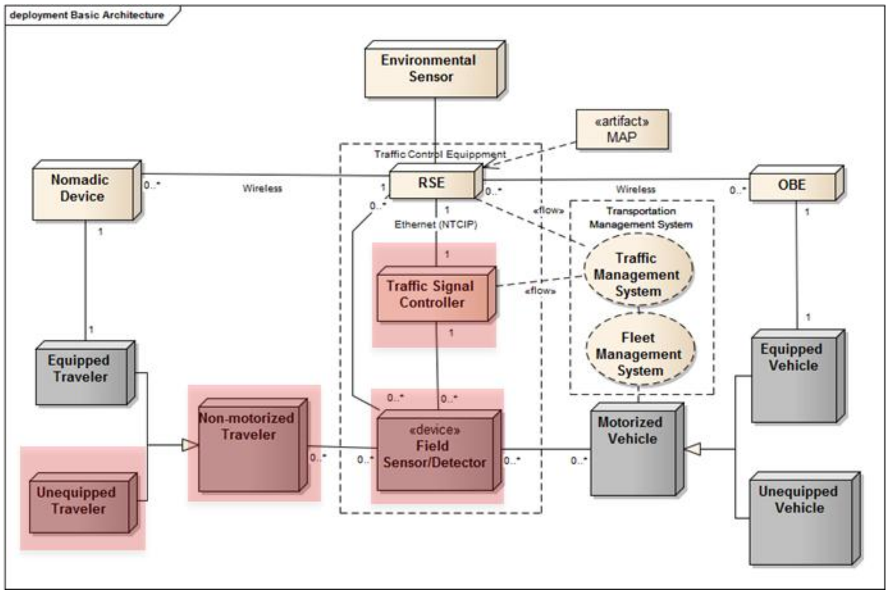

Figure 16 – Active Architecture Nodes for Unequipped Non-Motorized Traveler

11.3.2 Equipped Non-Motorized Traveler

The equipped non-motorized traveler architectural entity supports scenarios for a single pedestrian, groups of pedestrians, pedestrians with disabilities, special events, large platoons of pedestrians in urban areas, cyclists, and potentially intersections without dedicated pedestrian push-button infrastructure. A pedestrian, including a person or persons with visual or physical disabilities, walking toward an intersection may use a nomadic device containing a registered client application to activate the pedestrian signal. While approaching the intersection, the pedestrian activation application in the nomadic client alerts that he/she is near an instrumented intersection. The pedestrian then points the nomadic device towards the desired direction of travel and presses the “request service” button. An Alternative Basic Safety Message (ABSM – for pedestrians or pedalcyclists) and a Signal Request Messages (SRM) are sent to the RSE. The SRM indicates that the pedestrian is staged in one of the sidewalks at the entrance of the crosswalk. This informs the traffic signal controller to call the appropriate pedestrian phase. Typically, the pedestrian interval is ‘phase associated’ in order to minimize vehicle delays. In other applications, the pedestrian interval may be activated before traffic starts in order to better establish the presence of pedestrians (called delayed start of [vehicle] green). Also, priority may be designed to provide early activation of a pedestrian signal upon receiving an SRM from nomadic devices and/or provide longer pedestrian clearance interval for equipped pedestrians with disabilities (authorized nomadic devices). The RSE sends an SSM to the nomadic device to provide status of the request and impending signal.

The ABSM from the nomadic device can support the detection of the pedestrian's presence in the crosswalk and enable crosswalk phase extension if the pedestrian's presence has not ended within the pedestrian clearance time.

The active nodes for the Equipped Non-Motorized Traveler scenario are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 17. The Equipped Pedestrian Crosswalk Activation use case can be found in Section 13.3.3.

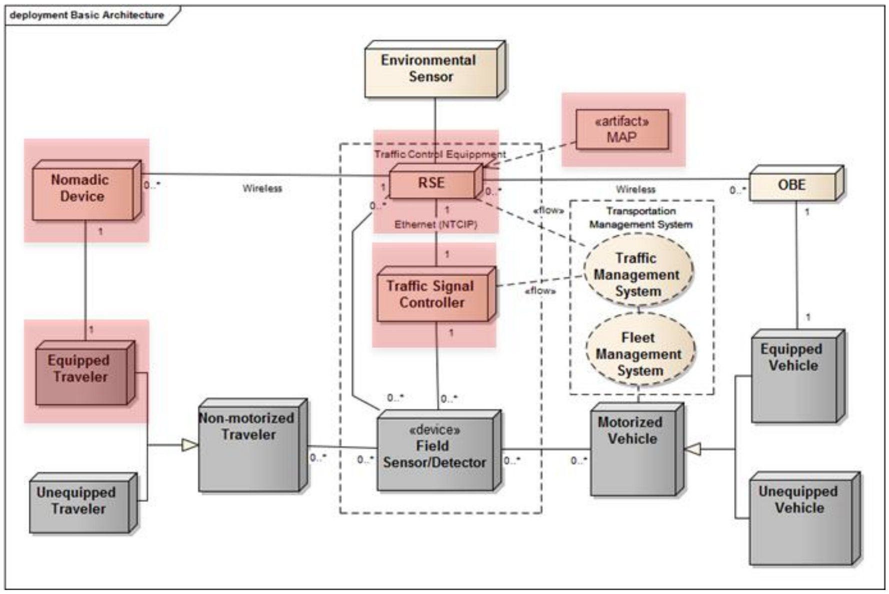

Figure 17 – Active Architecture Nodes for Equipped Non-Motorized Traveler

11.3.3 Equipped Bicyclist

In many situations cyclists can be helped to safely and efficiently travel through signalized intersections by the traffic signal system. At the present time, detecting and classifying cyclists that are near or at a signalized intersection is a major challenge. With the recent increases in bicycle usage in urban areas and changing laws in some parts of the country that require sufficient green time be for cyclist, MMITSS could play a vital role in ensuring safe and efficient service.

A cyclist approaching an intersection may use a nomadic device containing a client application to actuate the signal. While approaching the intersection, the bicycle traffic signal activation application in the nomadic client alerts the traffic signal controller that the cyclist is approaching an instrumented intersection. An Alternative Basic Safety Message (ABSM) and possibly a Signal Request Message (SRM) are sent to the RSE. The cyclist should not be required to press a button or otherwise engage the nomadic client application for the signal to provide service.

The ABSM provides the basic means for the traffic control system to be aware of the bicycle and provide actuation of a traffic signal phase. In some cases, it may be desired to send an SRM so that the cyclist can indicate a desired direction of travel (e.g., left turn). In cases where an SRM is sent to the RSE, the SRM indicates the desired direction of travel. This informs the traffic signal controller to call the appropriate phase. Depending on local policy, priority may be designed to provide early activation of a signal phase upon receiving an SRM from registered nomadic devices of cyclists. The RSE sends an SSM to the nomadic device to provide status of the request and impending signal. In a special case, where a cyclist using a nomadic device and indicating a desire to turn left at large multi-lane signalized intersection with actuated exclusive left turn signal phase could greatly benefit from MMITSS. By sending ABSM and SRM, it not only makes its turning intention known to the controller but also overcomes the challenge of bicycle detection and classification at instrumented intersections. MMITSS knows it has to service a bicycle not a vehicle. Different signal timing could be provided for cyclists in respect to pedestrians in one hand and vehicles on the other hand.

The use case for the Non-Equipped Non-Motorized Traveler can be found in Section13.3.3.

11.3.4 Inclement Weather Accommodations for Non-Motorized Travelers

In many parts of the country, inclement weather poses challenges to pedestrians that can be alleviated potentially by MMITSS. Imagine a windy winter day in Chicago with a windchill factor of -20°F and a pedestrian pushes the crosswalk button. Or perhaps it is a typical 115°F day in the summer in Phoenix with no shade in sight. Integrating weather sensors from the infrastructure, CV, and nomadic devices can provide useful input as to whether the TSC should give priority to the pedestrian or allow for extra crossing time to compensate for the strong headwind. During monsoon season in the southwest, it would be beneficial to accommodate the request of pedestrians waiting to cross to avoid the risk of splashing and dousing caused by passing cars.

The use case for the Inclement Weather Accommodations for Non-Motorized Travelers can be found in Section 13.3.3.

11.4 Freight Signal Priority Operational Scenarios

Technically, there are few differences between transit signal priority (TSP) and freight signal priority (FSP). The types of vehicles, consequences, and benefits of priority comprise the minor differences between these two modes. Transit needs to meet on-time performance to transport people reliably from point-to-point. Reducing intersection delay can assist with bus punctuality and schedule adherence. Since most freight is not limited to a particular route or schedule, stopping at a particular intersection (red signal) may be less of a hindrance to performance. However, heavy or loaded freight vehicles pose additional considerations to dilemma zones due to deceleration profiles, especially during inclement weather. As such, there are additional benefits to minimizing signalized stops on truck routes: enhanced pavement life, reduced intersection incursions, reduced red light running, reduced emissions, and reduced impact to other vehicular traffic. For these and regional economic reasons (e.g., ports, airports, distribution centers), MMITSS includes freight in the n-levels of priority available to manage multiple requests for consideration from multiple modes of travelers on signalized arterials. Working in conjunction with local transportation agencies, freight companies can use truck size, truck weight, vehicle dynamics, type of cargo (e.g., perishable, expedited, hazardous, and bulk), location, heading, time-of-day, weather and other factors to assign the appropriate level of priority. As developed in Section 11.0.2, an operating agency may designate a freight corridor where trucks are given a higher level of priority over prevailing traffic conditions. This type of policy can be used to encourage trucks to use certain corridors to improve safety and operations of other corridors. MMITSS integrates FSP under the same framework as TSP to facilitate and manage the n-levels of priority.

This section presents two types of FSP scenarios: Basic Freight Signal Priority and Coordinated Freight Signal Priority along a Signalized Truck Arterial. Use cases associated with these scenarios are presented in Section 13.3.4.

11.4.1 Basic Freight Signal Priority

Basic FSP includes two operational scenarios, including (1) single equipped truck approaches single intersection and (2) multiple equipped trucks approach single intersection. The latter scenario makes use of the prior scenario to accommodate priority requests from multiple equipped trucks.

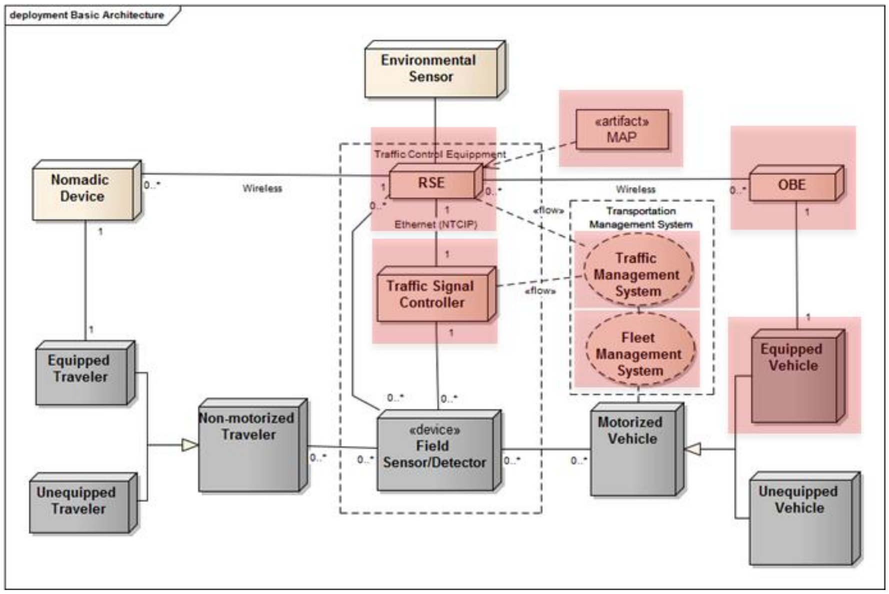

Figure 18 – Active Architecture Nodes for Basic Freight Signal Priority

11.4.1.1 Single Equipped Truck Approaches Single Intersection

Consider an equipped truck approaching an intersection. When the truck reaches the communications range, the OBE begins to receive the MAP and SPaT messages from the RSE and the RSE receives the BSM from the truck. The OBE continuously tracks the movement of the truck, estimates its arrival time at the stop bar, and matches the estimated arrival time with SPaT to determine the signal phase when the truck is going to arrive at the intersection. If the truck is projected to arrive at the intersection during the time just after the signal changes from green to the clearance and red intervals, , the OBE sends a SRM to the RSE. The SRM will include the level of priority which can differentiate the cases of (1) the truck cannot be safely stopped before the stop bar given its current distance to the stop bar and speed, and (2) the truck can be safely stopped. The RSE receives the SRM from the truck, and determines the best priority timing based on the prevailing traffic conditions and the level of priority requested by the truck. The RSE either holds the green for the truck direction if the level of requested priority indicates the truck cannot make a safe stop, or decides if the phase should terminate based on prevailing traffic conditions. When the truck clears the intersection, the OBE sends a cancel SRM to the RSE. The RSE receives the cancel SRM and manages the traffic signal controller to end the priority granting and returns to the normal traffic signal control.

The use case associated with this scenario can be found in Section 13.3.4.

11.4.1.2 Multiple Equipped Trucks Approach Single Intersection

Consider several equipped trucks approaching an intersection from the same or conflicted directions. Each of the equipped trucks can request priority as discussed in the previous Section. This scenario adds the intelligence on the RSE to prioritize the multiple requests (trucks that cannot make a safe stop will have a higher priority than those that can). The RSE keeps tracking the BSMs and SRMs from the trucks. MMITSS may group priority requests from different vehicles together to form pseudo-platoons that can be accommodated. There might be the case that two trucks approach the intersection from the same direction and both require green extension to avoid an unsafe stop. However, the traffic signal controller cannot accommodate both requests due to the phase maximum time constraint (the controller has to serve other traffic as well and cannot extend the phase forever). In this situation, MMITSS determines the best phase termination point to allow the leading truck to safely clear the intersection and sends a warning message to the following truck to advise the driver to decelerate earlier for a safe stop before the stop bar. The use case associated with this scenario can be found in Section 13.3.4.

11.4.2 Coordinated Freight Signal Priority along a Truck Arterial

Along a truck arterial where truck volume is high and intersections are closely spaced, coordinated FSP control providing truck green bands can minimize the number of stops for trucks traveling through the arterial and consequently lead to improved safety and mobility for the truck arterial. This scenario includes the basic FSP scenario described previously and adds intelligence on the roadside equipment to manage the truck green bands along the arterial. As with the basic FSP scenario, each of the equipped trucks determines the eligibility for priority and sends an SRM to the immediate downstream RSE. In contrast to the basic FSP scenario where the best priority timing plan is determined locally by the associated RSE, this scenario addresses coordinated FSP control through field-to-center communications. In this case, the traffic management system (i.e., MMITSS) collects requests for priority from connected RSEs, estimates the stop patterns for individual trucks, and forms sections of intersections to provide green bands for trucks. Coordinated FSP control timing plans will be optimized on the section-to-section basis to best facilitate trucks' movements along the arterial.

The use case associated with this scenario can be found in Section 13.3.4.

11.5 Emergency Vehicle Priority

11.5.1 Single Intersection Priority/Preemptions

Emergency vehicles include fire trucks, ambulances, police, and incident response teams. These vehicles respond to a broad variety of emergency situations. Typically multiple vehicles, maybe from different agencies, will respond to a single event. Traffic signal priority for emergency vehicles is currently a first-come, first-serve process where the traffic signal controller receives a call for service from a vehicle on one of the approaches to the intersection. Many systems use an infrared signal that is detected at a fixed location. Some newer systems use radio communications with GPS positioning to locate the approaching vehicle. When the traffic signal controller receives the call it will drop the signal from coordination, exit the current phase (without violating minimum green times), may drop pedestrian intervals, and serve the phase that has been preconfigured as the service phase given the input to the controller. If the controller is already in the desired phase, the controller will hold that phase until the call is cleared or some maximum time occurs.

In a connected vehicle system, emergency vehicles can be treated with a very high degree of priority while considering the current signal control state and traffic situation, including the possible arrival of multiple vehicles from the same or conflicting directions. This treatment relies on both improved communication and location capability, as well as improved signal control logic for priority based control.

When an equipped emergency vehicle in an active response state approaches an intersection, it first receives the MAP and SPaT messages from the RSE. Each emergency vehicle will broadcast continuously its BSM so that the intersection becomes aware of it as soon as it enters the RSE radio range. The BSM can also be received by other emergency vehicles to make them aware of each other.

The emergency vehicle (OBE) will use the MAP to determine current position, estimated time of arrival at the intersection stop bar, and direction of travel (if this is available from a navigation system). The vehicle forms a Signal Request Message (SRM) that is transmitted to the RSE. The RSE will manage multiple priority requests (from multiple vehicles) by sorting them by service phase (determined by the desired direction of travel – using the inlane and outlane SRM data). The signal request messages will be forwarded to the traffic controller (or logic), which will determine the best timing to serve the received set of requests. As new requests are received, or existing requests are satisfied or modified, the list of active requests is updated. When all of the emergency vehicle requests are served, the signal will return to normal service, which may include coordination or other (transit, freight) active priority requests. It is assumed that emergency vehicle requests override any other type of priority request.

It is assumed that an intersection equipped with connected vehicle technology would not be equipped with traditional preemption technology, since preemption control at an intersection will override almost all other forms of control, except for rail crossing preemption. It is also assumed that the emergency vehicles may cross the signal stop bar when the signal is red.

The active nodes for the Emergency Vehicle Priority scenarios are shown with highlighted boxes in the MMITSS Conceptual Architecture diagram in Figure 19. The associated use case for this scenario can be found in Section 13.3.5.

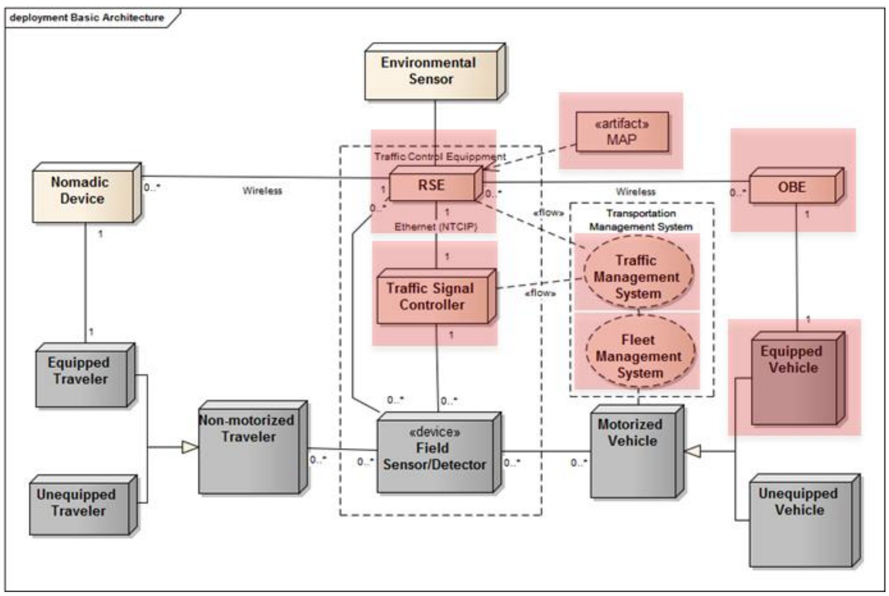

Figure 19 – Active Architecture Nodes for Emergency Vehicle Priority

11.5.2 Route Based Intersection Priority/Preemption

Based on the underlying logic of the other modal scenarios, the Single Intersection Preemption would be followed by a “multiple intersection preemption”. However, this logic would assume that the next traffic signal to be encountered is known. Such knowledge constitutes the basis of Route Based Intersection Preemption. Route based priority/preemption can benefit emergency vehicles when traffic conditions are severe (e.g., congestion) or when traffic signals are closely spaced. Route information must be available to the MMITSS either from the vehicle or from the dispatch (or fleet management system). It is assumed that the priority requests can be relayed through the traffic management system or using RSE-to-RSE backbone communications.

The Signal Request Messages can be sent to downstream signals, but the estimated arrival time may be inaccurate and require updating as the vehicle progresses along the route.

The use case for route based priority is similar to that of single intersection based priority, except that the requests need to be relayed to the downstream signals. This can be done through the traffic management system or using RSE-to-RSE communications.

12 Summary of Impacts

12.1 Impacts to System Users

Users, multi-modal travelers, should experience improved quality of service when MMITSS is operating as designed. Section 12.7 defines specific performance measures for the different travel modes. Travelers should believe that they are active participants in the traffic management system and they should have a positive understanding of how and why they receive the service from MMITSS.

12.2 Impacts to System Owners and Managers

The benefits of integrating connected vehicle data (BSM) to system owners are manifold. From a functionality perspective, the use of connected vehicle data provides enhanced reliability of detector-based systems through the introduction of redundancy in vehicle sensing and the ability to more accurately monitor system performance.

12.3 Impacts to System Operators

MMITSS will require maintenance resources or capabilities that are able to understand additional communications and control logic aspects of the system. The system operators will need additional training and tools to support configuration, monitoring, diagnostics, and repairs.

12.4 Impacts to System Interfaces

MMITSS will require well defined relationships between the Fleet Management Systems (EV dispatch, transit operations, and freight management systems) to determine a fair and effective hierarchy for priority requests. Establishment of a policy that is acceptable and beneficial to the stakeholders is an important consideration in establishing the effectiveness of MMITSS.

MMITSS will also have a role in cooperation with other dynamic mobility and safety applications. The interaction of these systems can improve MMITSS' ability to achieve the established goals and MMITSS can help the other systems achieve their established goals.

12.5 Shared and Cross-Cutting Impacts

Thus far, the MMITSS project has considered five categories of multi-modal users: ISIG, pedestrians, transit, freight, and emergency vehicles. Although these categories impose unique needs and requirements on the proposed MMITSS system, there are instances of shared or cross-cutting issues between two or more of these categories on more than one group of Stakeholders.

12.5.1 Shared Impacts: System Owners and Operators

General Maintenance Issues: One Stakeholder offered caution to the MMITSS team regarding the definition of a high level of availability. Based on experience, this Stakeholder stated that it can take days to fix traffic cabinets and traffic field equipment. Yet, another Stakeholder suggested that the MMITSS team define performance measures for maintenance turnaround times (e.g., MTTR) for equipped intersections due to safety implications.

Communication System Maintenance and Availability: The input from the Stakeholder Meeting reiterated that the expanded scope and reliance of an underlying communication protocol, capability, and system will increase the priority of the state-of-health, availability, and maintenance of this subsystem. Although the Stakeholders identified this need with the DSRC technology, it applies to whichever communication subsystem is defined in the Arizona and California testbeds. One Stakeholder offered that communications management is “a completely new requirement for transportation agencies and may be somewhat challenging for agencies.” Another Stakeholder added that adequate expertise in communication systems operation and maintenance may not exist in specific agencies.

Spare Parts: As identified during the Stakeholder Meeting, the definition, policy, and process for certifying spare parts and equipment is essential. Ongoing calibration and easy swap maintenance was requested.

12.6 Impacts to the Transportation Field

12.6.1 Enhancements and Extension of Capabilities

The proposed MMITSS system will incorporate recent advances in ITS and communication technologies to improve on existing TSP systems currently deployed and in use. MMITSS will also provide new opportunities to provide priority to freight vehicles, pedestrians, and emergency vehicles. The proposed improvements are realized through a comprehensive, multi-modal approach to corridor management. For example, the benefits of current TSP systems are geared toward individually equipped transit vehicles that approach a single signalized intersection on their routes. The MMITSS will consider priority control strategies beneficial to the entire corridor. As such, it can consider the current signal phases at nearby intersections and the presences of other nearby transit vehicles as well as at the next intersection. With MMITSS, it is possible to include capabilities to account for a variety of metrics such as passenger load and type of transit service, port schedule and type of cargo for freight vehicles, safety and access for blind pedestrians, and others.

12.6.2 Access to New Data Sources

As mentioned previously, the MMITSS provides a rich data set from both connected vehicles and interactions with infrastructure sensors. Access to the time synchronized data sets will prove useful to transportation researchers and practitioners in post-analysis, extended simulations, and test data.

12.7 Assessment of System Performance

12.7.1 ISIG Metrics and Performance Measures

During the ConOps Workshop on 7/18/12, the ISIG performance measures were refined in terms of peak period, all day, volume levels, and other refinements to make the measured values more discernible. As such, the ISIG goals, metrics, and performance measures discussed during the initial Stakeholder workshop have been updated and are shown in Table 3.

Intelligent Traffic Signal System (ISIG) Performance Measures	Average Stakeholder Input	MMITSS Phase 2 Goal	MMITSS Long-Term Goal
Overall Vehicle Delay (All Day)			
Overall Vehicle Delay (Peak Period)	-26.64%		
Number of Stops (All Day)			
Number of Stops (Peak Period)			
Throughput (All Day)			
Throughput (Peak Period)	23.05%		
Maximum Queue Length (All Day)			
Maximum Queue Length (Peak Period)	-21.00%		
Extent (spatial range) of Congestion (All Day)			
Extent of Congestion (Peak Period)	-23.38%		
Temporal Duration of Congestion (All Day)			
Temporal Duration of Congestion (Peak Period)	-26.71%		
Arterial Total Travel Time (All Day)			
Arterial Total Travel Time (Peak Period)			
Arterial Travel Time Variability (All Day)			
Arterial Travel Time Variability (Peak Period)			
Availability of Signal/System State of Health Monitoring (All Day)			

Table 3 - ISIG Performance Measures and Metrics

12.7.2 TSP Metrics and Performance Measures

As stated in the MMITSS Assessment Report, various deployment cases of TSP systems have demonstrated the TSP effectiveness in improving transit service quality. Other potential benefits of TSP deployments include reduced average transit delay, reduced transit delay variability, reduced travel time, reduced intersection delay, and improved schedule adherence. Each of these performance measures contribute to improved quality of transit service and customer satisfaction.

Transit Signal Priority (TSP) Performance Measures	Average Stakeholder Input	MMITSS Phase 2 Goal	MMITSS Long-Term Goal
Average Transit Delay (All Day)			
Average Transit Delay (Peak Period)	-26.95%		
Transit Delay Variability (All Day)			
Transit Delay Variability (Peak Period)	-32.67%		

Table 4 - TSP Performance Measures and Metrics

12.7.3 Pedestrian Mobility Metrics and Performance Measures

Pedestrian Mobility Performance Measures	Average Stakeholder Input	MMITSS Phase 2 Goal	MMITSS Long-Term Goal
Overall Pedestrian Delay (All Day)			
Overall Pedestrian Delay (Peak Period)	-24%		

Table 5 – Pedestrian Mobility Performance Measures and Metrics

12.7.4 Freight Signal Priority Metrics and Performance Measures

Freight Signal Priority Performance Measures	Average Stakeholder Input	MMITSS Phase 2 Goal	MMITSS Long-Term Goal
Overall Truck Delay (All Day)			
Overall Truck Delay (Peak Period)	-27.63%		
Freight/Goods Reliability (Peak Period)			
Freight-Intersection Accident Rates			
Dilemma Zone Incursions by Trucks			
Truck Stops at Signalized Intersections (All Day)			
Truck Stops at Signalized Intersections (Peak Period)			

Table 6 – Freight Signal Priority Performance Measures and Metrics

12.7.5 Emergency Vehicle Priority Metrics and Performance Measures

Emergency Vehicle Priority Performance Measures	Average Stakeholder Input	MMITSS Phase 2 Goal	MMITSS Long-Term Goal
Overall EV Delay (All Day)			
Overall EV Delay (Peak Period)	-29.33%		
EV Delay Variability (All Day)			
EV Delay Variability (Peak Period)	-26.18%		
EV Response Time (All Day)			
EV Response Time (Peak Period)			
EV Accident/Incidents at Intersections			

Table 7 – Emergency Vehicle Priority Performance Measures and Metrics

12.7.6 Cross-Cutting Performance Measures

Cross-Cutting Performance Measures	Average Stakeholder Input	MMITSS Phase 2 Goal	MMITSS Long-Term Goal
Data Availability and Usability	N/A		
MMITSS Data Security and Information Assurance	N/A		
MMITSS Reliability	N/A		
MMITSS Availability	N/A		
MMITSS Interoperability	N/A		
MMITSS MTTR	N/A		
Synchronized Time Source Availability	N/A		
Availability of MMITSS Performance Measures	N/A		

Table 8 – Cross-Cutting Performance Measures and Metrics

13 Appendices

13.1 Acronyms

ABSM	Alternate Basic Safety Message
AC	Alameda-Contra Costa (Transit)
ADA	Americans with Disabilities Act (1990)
ADT	Average Daily Traffic
AQ	Air Quality
APC	Automatic Passenger Counting
APS	Accessible Pedestrian Signals
APTA	American Public Transportation Association
ASC	Actuated Signal Controller
ATDM	Active Traffic and Demand Management
ATV	All-Terrain Vehicle
AVL	Automatic Vehicle Location
BMW	Bavarian Motor Works
BRT	Bus Rapid Transit
BSM	Basic Safety Messages
CAD	Computer Aided Dispatch
CBD	Central Business District
CC	Cross-Cutting
CICAS	Cooperative Intersection Collision Avoidance System
CONOPS	Concept of Operations
CTS	Cooperative Transportation System
CV	Connected Vehicle
DMA	Dynamic Mobility Applications
DOT	Department of Transportation
DSRC	Dedicated Short Range Communication
EMS	Emergency Medical/Management Services
ETA	Estimated Time of Arrival
EV	Emergency Vehicle
EVP	Emergency Vehicle Preemption
FHWA	Federal Highway Administration
FMS	Fleet Management System
FPS	Feet Per Second
FSP	Freight Signal Priority
FTA	Federal Transit Administration
FYA	Flashing Yellow Arrow
GID	Geometric Intersection Description
GIS	Geographic Information System
GM	General Motors
GPS	Global Positioning Systems
HAWK	High-Intensity Activated Crosswalk
HOV	High Occupancy Vehicle
IC	Information Center
ID	Identification
INFLO	Intelligent Network Flow Optimization
IRC	Inter-Regional Corridor
ISIG	Intelligent Traffic Signal System
ITS	Intelligent Transportation System
KPP	Key Performance Parameter
LOS	Level of Service
MAC	Media Access Control
MD	Maryland
MHz	Megahertz (10^6 Hertz)

MMITSS	Multi-Modal Intelligent Traffic Signal System
MOE	Measures of Effectiveness
MPH	Miles Per Hour
MUTCD	Manual on Uniform Traffic Control Devices
N/A	Not Available or Not Applicable
NCSU	North Carolina State University
NHTSA	National Highway Traffic Safety Administration
NTCIP	National Transportation Communications for ITS Protocol
NY DOT	New York Department of Transportation
OAC	Open Architecture Controller
OBE	On-Board Equipment
OBU	On-Board Unit
OD	Origin-Destination
OEM	Original Equipment Manufacturer
PATH	Partners for Advanced Transportation Technology
PFP	Pooled Fund Project
PFS	Pooled Fund Study
PI	Principal Investigator
PII	Personally Identifiable Information
PMP	Project Management Plan
POV	Privately Owned Vehicle
PST	Pacific Standard Time
R&D	Research and Development
REACT	Regional Emergency Action Coordinating Team
RFP	Request for Proposal
RHODES	Real-time Hierarchical Optimized Distributed Effective System
RSE	Roadside Equipment
RSU	Roadside Unit
RV	Recreational Vehicle
SIE	Systems and Industrial Engineering
SME	Subject Matter Expert
SPaT	Signal Phase and Timing
SRM	Signal Request Message
SSM	Signal Status Message
SVN	Subversion (PFP Repository with Version Control)
SyRS	System Requirements
TARDEC	Tank and Automotive Research, Development and Engineering Center
TFHRC	Turner-Fairbank Highway Research Center
TMC	Traffic Management Center
TMDD	Traffic Management Data Dictionary
TMS	Traffic Management System
TSC	Traffic Signal Controller
TSP	Transit Signal Priority
TTS	Time to Activate
TTI	Texas Transportation Institute
UA	University of Arizona
UC	University of California
USDOT	United States Department of Transportation
UVa	University of Virginia
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VCRM	Verification Cross Reference Matrix
VII	Vehicle-Infrastructure Integration
VLU	Vehicle Logic Unit
VDOT	Virginia Department of Transportation
VMT	Vehicle Miles Traveled

13.2 References

FHWA–HRT–11–044, "Investigating the Advanced Traffic Signal Control -- Examining the Effect of Traffic Probe Data on Traffic Signal Operations", http://www.fhwa.dot.gov/advancedresearch/pubs/11044/11044.pdf, April 2011

Grembek, Offer, Kun Zhou, Irene Li, Meng Li, Wei-Bin Zhang, "Red Light Running Collision Avoidance", California PATH Research Report UCB-ITS-PRR-2009-01.

Head, L. "Traffic Control in a VII Environment", Traffic Signal Systems Committee Workshop, TRB Annual Meeting – Washington, DC, Jan 2008.

Head, Larry, Douglas Gettman, Darcy M. Bullock, and Thomas Urbanik II. 2007. Modeling traffic signal operations with precedence graphs. *Transportation Research Record*, no. 2035: 10-18.

ITS America. (2005). Transit Signal Priority (TSP): A Planning and Implementation Handbook. Washington D.C.

Lee, Joyoung; Byungkyu Park; , "Development and Evaluation of a Cooperative Vehicle Intersection Control Algorithm Under the Connected Vehicles Environment," Intelligent Transportation Systems, IEEE Transactions on , vol.13, no.1, pp.81-90, March 2012.

Middleton, Dan, James Bonneson, and Hassan Charara. 2011. "New Evidence of Improvements in Dilemma Zone Protection by Detection-Control System." Transportation Research Record: Journal of the Transportation Research Board 2259, pp. 151–157. doi:10.3141/2259-14.

SAE J2735, "Dedicated Short Range Communications (DSRC) Message Set Dictionary", http://standards.sae.org/j2735_200911/, November 2009

Savari, SCSC, and University of Arizona, SBIR - 11.1-FH2 Augmenting Inductive Loop Vehicle Sensor Data with SPAT and GrID (MAP) via Data Fusion, Phase 1 Final Report, 2011.

Shelby, Steven G., Darcy M. Bullock, and Douglas Gettman. 2005. Resonant cycles in traffic signal control. *Transportation Research Record*, no. 1925: 215-226.

Smith, Harriet R., Humily, Brandon, and Ivanovich, Miomir, Transit Signal Priority (TSP): A Planning and Implementation Handbook, May 2005, USDOT

Venkatanarayana, R., H. Park, B. Smith, C. Skerrit and N. Ruhter, "Application of IntelliDrive to Address Oversaturated Conditions on Arterials," 90th TRB Annual Meeting, Washington DC, Jan 2011.

Welcome to the Systems Engineering Guidebook for ITS. Federal Highway Administration CA Division. 27 March 2012. <http://www.fhwa.dot.gov/cadiv/segb/views/process/index.htm>

Zhang, Liping, Kun Zhou, Wei-Bin Zhang and James A. Misener, "Dynamic All-Red Extension at Signalized Intersection: Probabilistic Modeling and Algorithm" California PATH Research Report UCB-ITS-PRR-2011-01.

13.3 Operational Scenario Use Cases

13.3.1 ISIG Use Cases

Use Case: Basic Signal Actuation – Unequipped Single Vehicle
ID: 11.1.1.1
Brief Description: This use case describes the basic traffic signal actuation by an unequipped vehicle.
Primary Actor: Unequipped Vehicle
Secondary Actors: Traffic Signal Controller
Precondition: 1. The intersection has an extension detector 250 feet from the stop bar 2. The designed operating speed is 35 mph 3. The traffic signal controller is programmed to extend the phase 5.0 seconds after the vehicle leaves the extension detector.
Main Flow: a. The use case begins when an Unequipped Vehicle crosses (exits) the extension detector on the approach to the intersection. b. If the service phase is not green, the detector actuation will place a call for the associated phase. This signal controller will serve the phase in the sequence as programmed, or configured, in the controller. c. If the service phase is green, the detector actuation will reset the extension (gap) timer to the 5.0 s (programmed value) d. If the service phase is green and there is a call on a conflicting phase, the maximum green timer will time its programmed value. When the maximum time is reached the phase will max out and advance to the yellow clearance interval. e. The use case ends
Post Condition: 1. The vehicle safely crosses the stop bar during a green signal or the vehicle is required to stop at a red signal
Alternative Flow:
Comments:

Use Case: Basic Signal Actuation – Single Equipped Vehicle
ID: Section 11.1.1.2
Brief Description: This use case describes the basic traffic signal actuation by a connected vehicle.
Primary Actor: Equipped Vehicle (OBE)
Secondary Actors: Traffic Signal Controller
Precondition: 1. The intersection has an extension detector 250 feet from the stop bar. 2. The designed operating speed is 35 mph. 3. The traffic signal controller is programmed to extend the phase 5.0 seconds after the vehicle leaves the extension detector.
Main Flow: a. The use case begins when an Equipped Vehicle enters the radio range of an RSE. b. The OBE receives MAP and SPaT messages from the RSE. c. The RSE receives Basic Safety Messages (BSM) from the OBE. d. The RSE tracks the OBE to estimate when the vehicle will arrive and wants to cross the intersection stop bar (note: route information is not assumed to be available). e. The RSE determines the appropriate traffic signal phase to serve the vehicle (translates BSM data into a phase request). f. The RSE calls the appropriate phase based on when the vehicle will arrive and the phase max time. g. The RSE matches the detector call to the OBE location and prevents the gap timer from timing the detection event. h. The RSE holds the phase green until the vehicle crosses the stop bar. i. The RSE updates the vehicles served performance measures. j. The use case ends.
Post Condition: 1. The vehicle safely crosses the stop bar during a green signal.
Alternative Flow: 1. (f) The Equipped vehicle changes speed and the RSE updates its travel time estimate. 2. (g) The OBE position and detector location do not match (errors) so the gap timer is allowed to time. (h) The phase is still held green. 3. (f) The Equipped Vehicle will not arrive during the green interval and the vehicle has to stop for a Red Signal. (i) The RSE updates the Delay and Stop performance measures. 4. (g) The RSE cannot match the detector call to the OBE location because the vehicle has changed route/path and the track is dropped.
Comments:

Use Case: Basic Signal Actuation – Multiple Equipped Vehicle Actuation
ID: Section 11.1.1.3
Brief Description: This use case describes the basic traffic signal actuation by several connected vehicles on different approaches to a traffic signal.
Primary Actor: Several Equipped Vehicles (OBEs)
Secondary Actors: Traffic Signal Controller
Precondition: 1. The intersection has extension detectors 250 feet from the stop bar on all approaches. 2. The designed operating speed is 35 mph. 3. The traffic signal controller is programmed to extend the phase 5.0 seconds after the vehicle leaves the extension detector.
Main Flow: a. The use case begins when any one of the Equipped Vehicles enters the radio range of an RSE. b. The following steps occur for each vehicle that approaches the intersection: i. The OBE receives MAP and SPaT messages from the RSE. ii. The RSE receives Basic Safety Messages (BSM) from the OBE. iii. The RSE tracks the OBE to estimate when the vehicle will arrive and wants to cross the intersection stop bar (note: route information is not assumed to be available). iv. The RSE determines the appropriate traffic signal phase to serve the vehicle (translates BSM data into a phase request). v. The RSE matches the detector call to the OBE location and prevents the gap timer from timing the detection event. vi. If the service phase is not timing (active), the RSE places a call for the phase based on when the vehicle will arrive and the phase max time. vii. If the service phase is timing, the RSE will hold the phase green until the vehicle crosses the stop bar or the phase max time or coordination force off point is reached unless the vehicle will not be able to reach the stop bar before the maximum time is reach in which case the phase will be allowed to terminate early (efficiency). c. The RSE updates the vehicles served performance measures. d. The use case ends.
Post Condition: 1. The vehicles safely cross the stop bar during a green signal.
Alternative Flow: 1. (b-iii.) An equipped vehicle changes speed and the RSE updates its travel time estimate. 2. (b-v.) The OBE position and the detector location do not match (errors) so the gap timer is allowed to time. (h) The phase is still held green. 3. (b-vii.) The Equipped Vehicle will not arrive during the green interval and the vehicle has to stop for a Red Signal. 4. (b) The RSE cannot match the detector call to the OBE location because the connected vehicle has changed route/path and the track is dropped. 5. (c) The RSE updates the Delay and Stop performance measures.
Comments:

Use Case: Coordinated Section of Signals
ID: Section 11.1.2
Brief Description: This use case describes how connected vehicles operate in a coordinated section of signals and how they can provide information for dynamic offset adjustment.
Primary Actor: Several Equipped Vehicles (OBEs) organized in a platoon
Secondary Actors: Section Traffic Signal Controller as part of the Traffic Management Center (TMC)
Precondition: 1. A group (platoon) of vehicles is traveling along the coordinated direction of travel in a traffic control section. [Note: A platoon will be defined as a group of vehicles that have short and similar headways between vehicles.] 2. Each traffic signal controller in the section has a coordination plan that consists of a cycle length, a set of phase splits, and an offset. The cycle length is common for the section. The phase splits are determined based on single intersection phase demand and queueing.
Main Flow: a. The use case begins when the group of vehicles (platoon) enters the coordinated section. The lead vehicle and trailing vehicle define the head and tail of the platoon, respectively. The BSMs from the equipped vehicles and vehicle count data from loop detectors are used to estimate the size of the platoon. b. Using BSM's from equipped vehicles in the platoon, the RSE tracks the movement of the identified platoon approaching the intersection and forwards the BSMs to the TMC. c. The TMC processes the BSMs to estimate performance measures related to platoon progression through the section. The performance measures include the stop frequency of platoons, queue length at individual intersections, and travel time of platoons between intersections. d. The TMC monitors the estimated performance measures over time, identifies the intersection(s) with inappropriate offset(s) causing disruption of platoon progression through the section. e. The TMC selects the most appropriate offsets for each intersection along the section. The selection of the offsets will take into consideration the queue discharging time at individual intersections and expected travel time between intersections. f. The TMC sends the desired offsets to the individual traffic signal controllers and each controller adjusts its offset accordingly. g. Repeat step b to f until the platoon exits the coordinated section, when the use case ends.
Post Condition: 1. A platoon of vehicles has progressed through a coordinated section of traffic signals and the coordination performance measures have been collected.
Alternative Flow: 1. (f) If progression is desired in both directions, the adjustment of the offset must consider a trade-off between the two directions of travel.
Comments:

Use Case: Congestion Control
ID: Section 11.1.3
Brief Description: One or more intersections are experiencing persistent phase failures on one or more movements. The traffic signal control system can take a variety of actions to reduce the duration and extent of the congestion. These actions include increasing the phase split and/or cycle length, managing the queues by metering at upstream intersections, and flushing (or other strategies) [Review NCHRP 3-79]. Phase Failure performance measures can be estimated more accurately using CV data by determining if the phase failure is caused by vehicles that arrived during the current cycle or of they were present in the previous cycle(s).
Primary Actor: Intersection Performance Measures (phase failures)
Secondary Actors:
Precondition: 1. The intersection has sufficient detection to identify phase failures, e.g. stop bar detection. 2. There are a sufficient number of CV's in the traffic stream to accurately identify true phase failures.
Main Flow: a. The use case begins when one or more traffic signal phases report a phase failure for more than X (configurable parameter, default = 3) cycles. A phase failure in a CV system should be defined as vehicles not being served in two or more cycles (as opposed to traditional measure of occupancy at stop bar detectors throughout the entire service (green time). b. The intersection controller evaluates alternative intersection strategies including: i. Free Operation ii. Split adjustment iii. Cycle length modification iv. Queue Management c. If one of the local strategies is evaluated to be feasible, the controller will implement the strategy. Performance measures are updated. Repeat step b until the phase failure persists or the queue exceeds upstream capacity. d. If phase failure persists and the queue grows to the upstream capacity the intersection will notify upstream traffic signal controllers to start metering flow into the congested region. Performance measures are updated. e. If the phase failure does not occur for Y (configurable parameter, default=2) cycles, the intersection will return to normal operation, and notify upstream signals to stop metering, and the use case ends. f. Performance measures are updated.
Post Condition: 1. One or more congested movements at an intersection are no longer congested and the queues are cleared every cycle.
Alternative Flow: 1. (b) The RSE cannot match the detector call to the OBE location because the vehicle is not equipped. The gap timer is allowed to time the programmed gap time. 2. (c) If one of the local strategies is not feasible, the controller will notify upstream signal controllers to start metering.
Comments:

Use Case: Dilemma Zone Protection
ID: Section 11.1.4
Brief Description: This use case is an extension of the Basic Signal Actuation use case with special considerations for dilemma zone protection.
Primary Actor: Several Equipped Vehicles (OBEs)
Secondary Actors: Traffic Signal Controller, Infrastructure Advance Warning Flashers
Precondition: 1. The intersection has a pair of dilemma zone detectors on the approach spaced such that vehicles between the first and second detector could stop if the signal changed to yellow. 2. The extension timer in the traffic signal controller is set to be long enough to allow a vehicle to safely cross the stop bar after exiting the second (downstream) detector.
Main Flow: a. The use case begins when any one of the Equipped Vehicles enters the radio range of an RSE. b. The following steps occur for each vehicle that approaches the intersection: i. The OBE receives MAP and SPaT messages from the RSE. ii. The RSE receives Basic Safety Messages (BSM) from the OBE. iii. The RSE tracks the OBE to estimate when the vehicle will arrive and want to cross the intersection stop bar (note: route information is not assumed to be available). iv. The RSE estimates the required stopping time/distance based on the vehicle characteristics. v. The RSE determines the appropriate traffic signal phase to serve the vehicle (translates BSM data into a phase request). vi. The RSE matches the detector call to the OBE location and prevents the gap timer from timing the detection event. vii. If the service phase is not timing (active), the RSE places a call for the phase based on when the vehicle will arrive and the phase max time. viii. If the service phase is timing, the RSE will hold the phase green until the vehicle crosses the stop bar or the phase max time or coordination force off point is reached unless the vehicle will not be able to reach the stop bar before the maximum time is reach in which case the phase will be allowed to terminate early (efficiency). ix. If the vehicle will not reach the stop bar before the maximum time occurs, the infrastructure based warning flashers are set to an on-state and a warning message is transmitted to the vehicle. c. The RSE updates the vehicles served performance measures. d. The use case ends.
Post Condition: 1. The vehicle legally cross the stop bar or the vehicle stops safely.
Alternative Flow: 1. (iii) An equipped vehicle changes speed and the RSE updates its travel time estimate. 2. (i) The OBE position and the detector location do not match (errors) so the gap timer is allowed to time the normal dilemma zone protection. (ii) The phase is still held green. 3. (a) The Equipped Vehicle will not arrive during the green interval and the vehicle has to stop for a Red Signal. (iii) The RSE updates the Delay and Stop performance measures.
Comments:

13.3.2 TSP Use Cases

Use Case: Basic TSP Scenario - Single Transit Vehicle at One Signalized Intersection
ID: Section 11.2.1.1
Brief Description: This use case describes the basic priority control for connected transit vehicles
Primary Actor: Transit Vehicle Equipped with On-board Equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller (TSC)
Precondition: 1. The traffic signal controller is programmed with a variety of priority control schemes such as early green, green extension, phase rotation, phase skipping, and etc. or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when an equipped transit vehicle enters the radio range of an RSE. b. The OBE receives MAP and SPaT messages from the RSE. c. The OBE send Basic Safety Messages (BSM). d. The OBE determines the eligibility for priority and sends a Signal Request Message (SRM) if needed. e. The RSE receives and tracks the BSM. f. The RSE receives SRM. g. The RSE manages and prioritizes requests (SRM) from multiple transit vehicles on the same or conflicting movements with the consideration of the prevailing traffic conditions and the requested level of priority (as determined by the vehicle and the established policy). h. The RSE determines the best signal timing plan to accommodate the active priority request and sends it to the TSC for further processing and execution. i. The TSC sends updated Signal Status Message (SSM) to the RSE and the RSE broadcasts the SSM to any connected vehicle (CV) approaching the intersection. j. The OBE receives the SSM and determines if and when the request will become active at the intersection. k. The OBE determines that the transit vehicle has cleared the intersection and sends a new SRM to cancel the priority request. l. The RSE receives the cancel SRM and sends it to the TSC. m. The RSE updates the transit vehicle served performance measures. n. The case ends.
Post Condition: 1. The transit vehicle safely crosses the stop bar during a green signal.
Alternative Flow: 1. (g) The transit vehicle changes speed and the RSE updates its priority timing based on travel time estimates. 2. (h) The transit vehicle will not arrive during green max window and vehicle has to stop at red signal. (i) The RSE updates the delay and stop performance measures.
Comments:

Use Case: Basic TSP Scenario - Multiple Transit Vehicles at One Signalized Intersection
ID: Section 11.2.1.1
Brief Description: This use case describes the basic priority control for multiple connected transit vehicles approaching one signalized intersection.
Primary Actor: Transit Vehicle Equipped with On-board Equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller(TSC)
Precondition: 1. The traffic signal controller is programmed with a variety of priority control schema such as early green, green extension, phase rotation, phase skipping, and etc. or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when an equipped transit vehicle enters the radio range of an RSE. b. The OBEs receive MAP and SPaT messages from the RSE. c. The OBEs send Basic Safety Messages (BSM). d. The OBEs determine the eligibility for priority and send a Signal Request Message (SRM). e. The RSE receives and tracks BSMs. f. The RSE receives SRMs. g. The RSE manages and prioritizes SRM requests from multiple transit vehicles on the same or conflicting movements, with the consideration of the prevailing traffic conditions, and passenger loads, service types, and schedule adherence of the requested vehicles. h. The RSE determines the best signal timing plan to accommodate the active priority request and sends it to the TSC for further processing and execution. i. The TSC sends updated SSM to the RSE and the RSE broadcasts the SSM. j. The OBE receives the SSM and determines if and when the request will become active at the intersection. k. The OBE determines that the transit vehicle has cleared the intersection and sends a new SRM to cancel the priority request. l. The RSE receives the cancel SRM and sends it to the TSC. m. The RSE updates the transit vehicles served performance measures. n. The case ends.
Post Condition: 1. Each transit vehicle safely crosses the stop bar during a green signal while experiencing a minimum delay.
Alternative Flow: 1. (g) The transit vehicle changes speed and the RSE updates its priority timing based on travel time estimates. 2. (h) The transit vehicle will not arrive during green max window and vehicle has to stop at red signal. (i) The RSE updates the delay and stop performance measures.
Comments:

Use Case: Variation of Basic TSP Scenario – TSP at Nearside Bus-Stop
ID: Section 11.2.1.1.1
Brief Description: This use case describes the TSP control for a connected transit vehicle at a nearside bus-stop.
Primary Actor: Transit Vehicle equipped with on-board equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller(TSC)
Precondition: 1. The traffic signal controller is programmed with a variety of priority control schemes such as early green, green extension, phase rotation, phase skipping, etc. or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when an equipped transit vehicle enters the radio range of an RSE. b. The OBE receives MAP and SPaT messages from the RSE. c. The OBE send Basic Safety Messages (BSM). d. The OBE determines the eligibility for priority and sends a Signal Request Message (SRM) if needed. The SRM contains the level of priority requested. e. The RSE receives and tracks the BSM. f. The RSE receives SRM containing the level of priority. g. The RSE determines the needs for advancing the green phase to clear the queue in front of the transit vehicle to allow the vehicle entering the near-side stop. h. Upon finishing passenger loading and alighting (door closed), the OBE determines the readiness of the bus to move and sends an SRM. i. The OBE determines the eligibility for priority and sends a Signal Request Message (SRM) if needed. The SRM contains the level of priority requested. j. The RSE manages priority to allow the bus clear the intersection with strategies including green extension or early green treatment for bus-stop in the mixed traffic lane, or special phase for the transit vehicle to move out of the pullout prior to non-transit traffic on the same movement. k. The OBE determines that the transit vehicle has cleared the intersection and sends a new SRM to cancel the priority request. l. The RSE receives the cancel SRM and sends it to the TSC. m. The RSE updates the transit vehicles served performance measures. n. The case ends.
Post Condition: 1. The transit vehicle moves safely out from the bus stop with reduced intersection delay.
Alternative Flow: 1. (d) If the bus is not eligible, or priority is not needed, the use case ends.
Comments:

Use Case: Variation of Basic TSP Scenario for Transit Buses - Transit Vehicle Special Signal Treatment for Protected Left-Turn
ID: Section 11.2.1.1.2
Brief Description: This use case describes the special priority control for a connected transit vehicle making a protected left-turn
Primary Actor: Transit Vehicle equipped with on-board equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller(TSC)
Precondition: 1. The traffic signal controller is programmed with a variety of priority control schemes such as early green, green extension, phase rotation, phase skipping, and etc. or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when an equipped transit vehicle enters the radio range of an RSE. b. The OBE receives MAP and SPaT messages from the RSE. c. The OBE send Basic Safety Messages (BSM). d. The OBE determines the eligibility for priority and sends a Signal Request Message (SRM) if needed. The SRM contains the level of priority requested The RSE receives and tracks the BSM. e. The RSE determines the needs for advancing the green phase to clear the queue in front of the transit vehicle to allow the vehicle entering the left-turn pocket, and manages coordinated priority timing between the through and left-turn movements. f. The OBE determines that the bus has cleared the intersection and sends a new SRM to cancel the priority request. g. The RSE receives the cancel SRM and sends to the TSC. h. The TSC ends priority control and returns to normal traffic signal control. i. The RSE updates the transit vehicle served performance measure. j. The case ends.
Post Condition: 1. The transit vehicle makes a safe left-turn with reduced intersection delay.
Alternative Flow: 1.
Comments:

Use Case: TSP for Rail Crossings in Urban Areas
ID: Section 11.2.2.1
Brief Description: This use case describes the priority control for highway/transit rail crossing in urban areas.
Primary Actor: Transit Rail Vehicle equipped with On-Board Equipment (OBE)
Secondary Actors: Road Side Equipment (RSE), Traffic Signal Controller (TSC) & Grade Crossing Interconnect
Precondition: 1. The traffic signal controller is programmed with rail preemption that incudes track clearance, dwell, and exit phases as well as a variety of priority control scheme such as early green, green extension, phase rotation, phase skipping, and etc. or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when an equipped transit rail vehicle enters the radio range of an RSE. b. The OBE receives MAP and SPaT messages from the RSE. c. The OBE send Basic Safety Messages (BSM). d. The OBE determines the eligibility for priority and sends a Signal Request Message (SRM) if needed. The SRM contains the level of priority requested The RSE receives and tracks the BSM. e. The RSE manages and issues priority based on prevailing traffic conditions and the designated level of priority, and sends priority timing to the Grade Crossing Interconnect. f. The Interconnect receives and sends priority timing to the TSC for execution. g. The OBE determines that train has cleared the crossing and sends a cancel SRM. h. The RSE receives the cancel SRM and sends to the Interconnect. i. The Interconnect receives and sends the cancel SRM to the TSC. j. The TSC receives the cancel SRM, ends priority control, and returns to normal traffic signal control. k. The RSE updates the transit vehicle served performance measures. l. The case ends.
Post Condition: 1. The transit vehicle travels safely through the intersection while experiencing no stop or a minimum delay.
Alternative Flow: 1. (g) The transit rail vehicle changes speed on an approach to one or more signalized intersections and the RSEs update their priority timing based on travel time estimates. 2. (i) The transit vehicle will not arrive during priority window and has to stop at a red signal. (j) The RSE updates the delay and stop performance measures.
Comments:

Use Case: Extended TSP Scenario - Single Transit Vehicle at a Section of Signalized Intersections
ID: Section 11.2.3
Brief Description: This use case describes the basic priority control for a connected transit vehicle travelling through a section of signalized intersections.
Primary Actor: Transit Vehicle Equipped with On-board Equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller (TSC)
Precondition: 1. Multiple signalized intersections are equipped with RSEs and have RSE-to-RSE communication enabled. 2. The RSEs store transit route GIS data or this data is available from the transit management system. 3. The traffic signal controllers in the section are programmed with a variety of priority control schemes such as early green, green extension, phase rotation, phase skipping, and etc. or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when an equipped transit vehicle enters the radio range of an RSE. b. The OBE receives MAP and SPaT messages from the immediate approaching RSE. c. The OBE sends Basic Safety Messages (BSM). d. The OBE determines the eligibility for priority and sends a Signal Request Message (SRM) containing the level of priority. e. The RSE receives and tracks BSM. f. The RSE receives an SRM and forwards the SRM to the TMC. g. The Traffic Management Center (TMC) forms a section of signalized intersections based on patterns of transit stops along the route. h. The TMC manages and prioritizes requests (SRM) from the transit vehicles to issue priority based on prevailing traffic conditions at a section of signalized intersections and the requested level of priority (as determined by the vehicle and the established policy). i. The TMC determines the best coordinated signal timing strategy along the section of signalized intersections to accommodate the active priority request. j. The TMC sends priority timing to the traffic signal controllers (via RSE-to-RSE communication) for further processing and execution. k. The TSC sends updated SSM to the RSE and the SSM is relayed to the OBE. l. The OBE receives the SSM and determines if and when the request will become active at the intersection. m. The OBE determines that the transit vehicle has cleared the intersection and sends a new SRM to cancel the priority request. n. The RSE receives the cancel SRM and sends it to the TSC. The TSC resumes normal operations. o. The RSE updates the transit vehicles served performance measures. p. The case ends.
Post Condition: 1. The transit vehicle safely travels through a section of signalized intersections.
Alternative Flow: 1. (h) The TMC receives levels of priority associated with each active priority request from the transit Fleet Management systems and uses this information to manage and prioritize requests (SRM). 2. The transit vehicle will not arrive during green max windows at one or more signalized intersections and has to stop at red signal. (o) The RSE updates the delay and stop performance measures.
Comments:

Use Case: Extended TSP Scenario - Multiple Transit Vehicle at a Section of Signalized Intersections
ID: Section 11.2.3
Brief Description: This use case describes the basic priority control for multiple connected transit vehicles travelling through a section of signalized intersections.
Primary Actor: Transit Vehicle Equipped with On-board Equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller (TSC)
Precondition: 1. Multiple signalized intersections are equipped with RSEs and have RSE-to-RSE communication enabled. 2. The RSEs store transit route GIS data or this data is available from the transit management system. 3. The traffic signal controllers in the section are programmed with a variety of priority control schema such as early green, green extension, phase rotation, phase skipping, and etc. or the traffic signal controllers have an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when an equipped transit vehicle enters the radio range of an RSE. b. The OBEs receives MAP and SPaT messages from the immediate approaching RSE. c. The OBE sends Basic Safety Messages (BSM). d. The OBE determines the eligibility for priority and sends a Signal Request Message (SRM) which containing the level of priority to the immediate RSE. e. The RSE receives and tracks BSMs from multiple transit vehicles. f. The RSE receives SRMs from multiple vehicles and forwards them to the TMC. g. The TMC forms sections of signals based on characteristics of received SRMs. h. The TMC manages and prioritizes multiple SRMs to issue priority based on prevailing traffic conditions at sections and the requested level of priority (as determined by the vehicle and the established policy). i. The TMC determines the coordinated signal timing strategy for sections to accommodate the multiple requests for priority. j. The TMC sends priority timing to the traffic signal controllers for further processing and execution. k. The TSC sends updated SSM to the RSEs and the SSM is relayed to the OBEs. l. The OBEs receives the SSMs and determines if and when the requests will become active at each intersection. m. The OBE determines that a transit vehicle has cleared an intersection and sends a new SRM to cancel the priority request. n. The RSE receives the cancel SRM and sends it to the TSC. The TSC either resumes normal operations or continues to provide priority for other active requests. o. The RSE updates the transit vehicles served performance measures. p. The case ends.
Post Condition: 1. The transit vehicles safely travel through a section of signalized intersections.
Alternative Flow: 1. (h) The TMC receives levels of priority associated with each active priority request from the transit Fleet Management systems and use this information to manage and prioritize multiple requests (SRMs) 2. (j) One or more transit vehicles changes speed on approaches to one or more signalized intersections and the RSEs update their priority timing based on travel time estimates. 3. One or more transit vehicles will not arrive during green max windows at one or more signalized intersections and has to stop at red signal. (o) The RSE updates the delay and stop performance measures.
Comments:

13.3.3 Pedestrian Mobility Use Cases

Use Case: Basic Signal Actuation – Unequipped Non-Motorized Traveler
ID: Section 11.3.1
Brief Description: This use case describes the basic traffic signal actuation by an unequipped non-motorized traveler (pedestrian, bicycle, or other traveler).
Primary Actor: Unequipped Traveler
Secondary Actors: Traffic Signal Controller
Precondition: 1. The intersection is equipped with pedestrian or bicycle push buttons, or pedestrians or bicycle sensors.
Main Flow: a. The Use Case begins when an Unequipped Traveler presses the pedestrian or bicycle push buttons or is detected by a pedestrian or bicycle sensor. b. The Traffic Signal Controller will serve the pedestrian call the next time the associated service phase starts timing or the desired phase for the cyclists. c. When the pedestrian interval starts timing, the pedestrian signal will display WALK for a preprogrammed amount of time, then FLASHING DON"T WALK, for a preprogrammed amount of time, or the desired phase for the cyclist starts. d. The pedestrian signal will display the DON'T WALK display at all other times. e. The use case ends.
Post Condition: 1. The unequipped traveler crosses the street in the direction of the pedestrian display or the cyclist travels through the instrumented intersection in the desired direction.
Alternative Flow:
Comments:

Use Case: Equipped Pedestrian Signal Activation
ID: Section 11.3.2
Brief Description: This use case describes the basic logic for activation of pedestrian crosswalk triggered by nomadic devices.
Primary Actor: Equipped Pedestrian (handheld nomadic device with authorized application)
Secondary Actors: Traffic Signal Controller (TSC)
Precondition: 1. The traffic signal controller is programmed with a variety of priority control schemes such as early green, green extension, phase rotation, phase skipping, and etc. or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The Use Case begins when an Equipped Pedestrian approaches the cross walk near an intersection. b. As the Equipped Pedestrian approaches the intersection: i. The handheld device receives MAP and SPaT messages from the RSE. ii. As the pedestrian arrives at the intersection, they point the nomadic device toward the intended direction of travel, and pushes a key on the nomadic device to send an SRM. iii. The RSE receives Alternative Basic Safety Messages (ABSM) and Signal Request Message (SRM) from the nomadic device. iv. The RSE determines the appropriate traffic signal phase to serve the pedestrian (translates SRM data into a phase request). v. The RSE determines which SRM's (from multiple) is to be served. vi. The RSE notifies the traffic signal controller (or logic) of the active requests including desired phase and service time. vii. The RSE transmits a status message (SSM) with information about which pedestrian requests will be served and wait time to the corresponding nomadic device(s). viii. The controller activates crosswalk light. ix. The RSE continuously receives ABSM from the nomadic device and extends the crosswalk phase if pedestrian presence has not ended within the minimum clearance time. c. The RSE updates the pedestrian served performance measures. d. The use case ends.
Post Condition: 1. The Equipped Pedestrian crosses the intersection safely using the crosswalk.
Alternative Flow: 1. Interrupt – A pedestrian may cancel the call at any time. The nomadic device will send an SRM cancel service request. 2. Pedestrians with disabilities may use authorized nomadic devices to request earlier or a longer than normal crossing time.
Comments:

Use Case: Equipped Bicyclist Signal Activation
ID: Section 11.3.3
Brief Description: This use case describes the basic logic for cyclists equipped with nomadic devices.
Primary Actor: Equipped Bicyclist handheld nomadic device with registered application
Secondary Actors: Traffic Signal Controller (TSC)
Precondition: 1. None
Main Flow: a. The Use Case begins when an Equipped Bicyclist approaches an intersection. b. As the Equipped Bicyclist approaches the intersection: i. The handheld device receives MAP and SPaT messages from the RSE. ii. Bicyclist is informed of the arrival at the intersection, pointing the nomadic device toward the intended direction of travel, and pushes a key on the nomadic device to send an SRM. iii. The RSE receives Alternative Basic Safety Messages (ABSM) and Signal Request Message (SRM) from the nomadic device, including estimates of time to arrival of the Cyclist at the stop bar, and determines Cyclist's intended direction. iv. The RSE determines the appropriate traffic signal phase to serve the Cyclist (translates SRM data into a phase request). v. The RSE determines which SRM's (from multiple) is to be served (Priority ranking? Or maximum number). vi. The RSE notifies the traffic signal controller (or logic) of the active requests including desired phase and service time. vii. The RSE transmits a signal status message (SSM) with information about which Cyclist requests will be served and wait time to the corresponding nomadic device(s). viii. The controller activates the phase for requested direction. ix. The RSE continuously receives ABSM from the nomadic device and extends the phase if Bicyclist presence has not ended within the minimum clearance time. c. The RSE updates the Bicyclist served performance measures. d. The use case ends.
Post Condition: 1. The Equipped Bicyclist crosses the intersection safely.
Alternative Flow: 1. (ix) The nomadic device updates the ABSM with new arrival information based on a change of speed or route change. 2. Interrupt – A Bicyclist may cancel the call at any time. The nomadic device will send an SRM cancel service request.
Comments:

Use Case: Inclement Weather Accommodations for Non-Motorized Travelers
ID: Section 11.3.4
Brief Description: This use case describes the logic for accommodating pedestrians during inclement weather.
Primary Actor: Equipped Pedestrian handheld nomadic device with registered application
Secondary Actors: Traffic Signal Controller (TSC)
Precondition: 1. Infrastructure-based weather sensors, CV weather sensors, and/or nomadic devices provide verification of inclement weather near intersection. 2. Weather conditions impact a pedestrian's ability to cross the street in the normally allocated time.
Main Flow: a. The Use Case begins when an Equipped Pedestrian approaches the cross walk near an intersection. b. As the Equipped Pedestrian approaches the intersection: i. The handheld device receives MAP and SPaT messages from the RSE. ii. Pedestrian is informed of the arrival at the intersection, pointing the nomadic device toward the intended direction of travel, and pushes a key on the nomadic device to send an SRM. iii. The RSE receives Alternative Basic Safety Messages (ABSM) and Signal Request Message (SRM) from the nomadic device, including estimates of time to arrival of the pedestrian at the crosswalk, and determines Pedestrian's intended direction. iv. The RSE determines the appropriate traffic signal phase to serve the pedestrian (translates SRM data into a phase request). v. The RSE determines the impact of the weather conditions (e.g. direction of wind/rain/snow) on a pedestrian in the desired direction of travel. vi. The RSE notifies the traffic signal controller (or logic) of the active requests including desired phase and weather modified service time. vii. The RSE transmits a status message (SSM) with information about which pedestrian requests will be served and wait time. viii. The controller activates crosswalk light. ix. The RSE continuously receives ABSM from the nomadic device and extends the crosswalk phase if pedestrian presence has not ended within the minimum clearance time. c. The RSE updates the pedestrian served performance measures. d. The use case ends.
Post Condition: *1.* The Pedestrian crosses the intersection efficiently and safely during inclement weather.
Alternative Flow: *1.* (iii) The nomadic device updates the ABSM with new arrival information based on a change of speed or route change. *2.* Interrupt – A pedestrian may cancel the call at any time. The nomadic device will send an SRM cancel service request.
Comments:

13.3.4 Freight Signal Priority Use Cases

Use Case: Basic FSP Scenario - Single Equipped Truck Approaches an Intersection
ID: Section 11.4.1.1
Brief Description: This use case describes the basic signal priority control for a connected truck approaching an intersection
Primary Actor: Truck Equipped with On-board Equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller (TSC)
Precondition: 1. The traffic signal controller is programmed with a variety of priority control schema such as early green and green extension or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when an equipped truck enters the radio range of an RSE. b. The OBE receives MAP and SPaT messages from the RSE. c. The OBE send Basic Safety Messages (BSM) to the RSE. d. The OBE determines the eligibility for priority and sends a Signal Request Message (SRM) if needed. The SRM includes the level of requested priority which can differentiate the case that the truck can or cannot make a safe stop before the stop bar. e. The RSE receives and tracks the BSM. f. The RSE receives SRM and determines the best signal timing plan to accommodate the active priority request, based on the prevailing traffic conditions and the level of requested priority. g. The RSE sends the priority timing plan to the TSC for further processing and execution. h. The TSC sends updated SSM to the RSE and the RSE broadcasts the updated SPaT messages. i. The OBE receives and tracks SPaT to determine if and when the request will become active at the intersection. j. The OBE determines that the truck has cleared the intersection and sends a cancel SRM to the RSE. k. The RSE receives the cancel SRM and sends it to the TSC. l. The TSC ends the priority granting and returns to the normal traffic signal control. m. The RSE updates the truck served performance measures. n. The case ends.
Post Condition: 1. The truck avoided an unnecessary stop and safely cleared the intersection, or 2. The truck made a safe stop before the stop bar and then safely cleared the intersection with reduced intersection delay.
Alternative Flow: 1. (e) The truck changes speed and the RSE updates its priority timing plan based on travel time estimates. 2. (f) If the TSC cannot accommodate the priority request, the RSE sends a warning to the OBE to advice the driver decelerating earlier for a safe stop before the stop bar. The OBE can re-send a SRM if needed (repeat from step d).
Comments:

Use Case: Basic FSP Scenario - Multiple Equipped Trucks Approach an Intersection
ID: Section 11.4.1.2
Brief Description: This use case describes the basic signal priority control for multiple connected trucks approaching an intersection.
Primary Actor: Trucks Equipped with On-board Equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller(TSC)
Precondition: 1. The traffic signal controller is programmed with a variety of priority control schema such as early green and green extension or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when more than one equipped trucks enters the radio range of an RSE. b. The OBEs receives MAP and SPaT messages from the RSE. c. The OBEs sends Basic Safety Messages (BSM) to the RSE. d. The OBEs determine the eligibility for priority and send a Signal Request Message (SRM) if needed. The SRM shall include the level of requested priority which can differentiate the case that the truck can or cannot make a safe stop before the stop bar. e. The RSE receives and tracks BSMs from multiple trucks. f. The RSE receives SRMs, manages and prioritizes SRM requests from multiple trucks. Request prioritization will consider the prevailing traffic conditions and the levels of requested priority. g. The RSE determines the best signal timing plan to accommodate the active priority requests and sends it to the TSC for further processing and execution. h. The TSC sends updated SSM to the RSE and the RSE broadcasts updated SPaT messages. i. The OBE receives and tracks the SPaT messages and determines if and when the request will become active at the intersection. j. The OBE determines that the truck has cleared the intersection and sends a cancel SRM to the RSE. k. The RSE receives the cancel SRM and sends it to the TSC. l. The TSC ends the granting of the active priority. m. The RSE repeats steps g & i for remaining active priority requests. n. The RSE updates the trucks served performance measures. o. The case ends.
Post Condition: Each of the equipped trucks either: 1. avoided an unnecessary stop and safely cleared the intersection, or 2. made a safe stop before the stop bar and then safely cleared the intersection with reduced intersection delay.
Alternative Flow: 1. (g) Trucks change speed and the RSE updates priority timing plan based on travel time estimates. 2. (h) If the TSC cannot accommodate the priority request from a truck, the RSE sends a warning to the associated OBE to advice the driver decelerating earlier for a safe stop before the stop bar. The OBE can re-send a SRM if needed (repeat from step d).
Comments:

Use Case: Coordinated FSP Scenario
ID: Section 11.4.2
Brief Description: This use case describes the priority control for multiple connected trucks travelling through a signalized truck arterial.
Primary Actor: Trucks Equipped with On-board Equipment (OBE)
Secondary Actors: Road Side Equipment (RSE) & Traffic Signal Controller (TSC)
Precondition: 4. The truck arterial is equipped with multiples RSEs and has RSE-to-RSE communication enabled. 5. The traffic signal controllers are programmed with a variety of priority control schema such as early green and green extension or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: q. The use case begins when an equipped truck enters the radio range of an RSE along the arterial. r. The OBE receives MAP and SPaT messages from the immediate downstream RSE. s. The OBE sends Basic Safety Messages (BSM) to the downstream RSE. t. The OBE determine the eligibility for priority and send a Signal Request Message (SRM) to the downstream RSE. The SRM shall include the level of requested priority which can differentiate the case that the truck can or cannot make a safe stop before the stop bar. u. The RSE receives and tracks BSMs from multiple trucks. v. The RSEs receives SRMs and communicate with each other to estimate the stop patterns of equipped trucks along the arterial. w. The RSEs jointly form sections of intersections based on the estimated trucks' stop patterns, and determine the best coordinated priority timing plans for each of the signal sections along the arterial. x. The RSE sends priority timing plan to the associated traffic signal controller for further processing and execution. y. The TSC sends updated SSM to the RSE and the RSE broadcasts the updated SPaT messages. z. The OBE receives and tracks the SPaT messages, and determines if and when the request will become active at the intersection. aa. The OBE determines that the truck has cleared the intersection and sends a cancel SRM to the immediate RSE. bb. The RSE receives the cancel SRM and sends it to the TSC. cc. The TSC ends the granting of the active priority. dd. The RSE repeats steps g & i for remaining active priority requests. ee. The RSE updates the trucks served performance measures. ff. The case ends.
Post Condition: 1. The trucks safely travel through the arterial while experiencing minimum delays reduced number of stops for a red signal.
Alternative Flow: 4. (g) Trucks change speed and the RSEs update coordinated priority timing plans based on truck travel time and stop pattern estimates. 5. (h) If the TSC cannot accommodate the priority request from a truck, the RSE sends a warning to the associated OBE to advice the driver decelerating earlier for a safe stop before the stop bar. The OBE can re-send a SRM if needed (repeat from step d)
Comments:

13.3.5 Emergency Preemption Use Cases

Use Case: Emergency Vehicle Priority – Single or Multiple Vehicles
ID: 11.5.1 and 11.5.2
Brief Description: This use case describes the basic logic for single intersection based emergency vehicle priority (preemption) with multiple vehicles
Primary Actor: Emergency Vehicle
Secondary Actors: Traffic Signal Controller
Precondition: 1. Emergency Vehicle is in Active Response Mode 2. The traffic signal controllers are programmed with a variety of priority control schema such as early green and green extension or the traffic signal controller has an intelligent algorithm for providing priority signal timing for priority requests.
Main Flow: a. The use case begins when any one of the Equipped Emergency Vehicles (EV) enters the radio range of an RSE. b. The following steps occur for each EV that approaches the intersection: i. The OBE receives MAP and SPaT messages from the RSE. ii. The RSE receives Basic Safety Messages (BSMs) from the OBE. iii. The OBE computes the estimated arrival time (min,max) and desired movement (inlane, outlane) as available. iv. The OBE determine the eligibility for priority and established the proper level of priority. v. The OBE sends a Signal Request Message (SRM) to the RSE. vi. The RSE determines the appropriate traffic signal phase to serve the vehicle (translates SRM data into a phase request). vii. The RSE determines which SRMs (from multiple vehicles) can be served (Priority ranking? Or maximum number). viii. The RSE notifies the traffic signal controller (or logic) of the active requests including desired phase and service time. ix. The RSE transmits a status message (SSM) with information about which requests will be served (feedback to the vehicle). c. The RSE updates the vehicles served performance measures. d. The use case ends.
Post Condition: 1. The EVs safely cross the stop bar.
Alternative Flow: 1. (iii.) The OBE updates the SRM with new arrival information based on a change of speed or route change. 2. (iv) If the OBE determines that the vehicle is not eligible for priority, the use case ends and the EV operates as any normal vehicle. 3. Interrupt – An emergency vehicle may terminate its emergency status at any time. The OBE will send an SRM cancel service request.
Comments:

13.4 Stakeholder Input Traceability Matrix

13.4.1 Stakeholder Input Traceability Matrix – ISIG

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
1.1.1		5	Intelligent Traffic Signals are more than just adaptive signal control.
1.1.2		11.1.2	It is important to remember that isolated intersection operation is not usually the optimal approach in a dense urban environment where signal operation needs to look at a larger population of signals and a managed implementation - i.e., the central systems need to optimize the network.
1.1.3			*MMITSS should* incorporate flexible multi-objective optimization that can be altered depending on the operational conditions: bad weather, code red AQ, special event, and so on.
1.1.4		11.1.2 11.1.3	*Connected vehicles can provide* optimization of section based on known arrival times of vehicles.
1.1.5		11.1.2 11.1.3	*Connected vehicles can provide* second-by-second optimization, based on real-time vehicle arrivals if high enough market penetration.
1.1.6			*Connected vehicles can provide* dynamic re-routing.
1.1.7		11.1.3	If the density of vehicles is present - then we can determine which areas are "busy" and where there is/is not capacity - faster detection of incidents - so we can support network optimization not just a single arterial.
1.1.8		11.1.3	Most current signal timing is based on volumes. Until there is 100 percent market penetration, connected vehicles will not be able to provide volume information. Therefore, looking into prior research related to using travel times or speed profiles as the basis for signal timing would be important.
1.1.9		11.1.3	A traffic signal system should include existing detection systems already in place, identify congestion hot points and implement appropriate signal timing, arterial travel-time and delay monitoring, passage of emergency vehicles through the signals with minimal disruptions to commuter traffic.
1.1.10		11.1.2 11.1.3	*Connected vehicles can provide intersection control improvements to include the* number of vehicles approaching the intersection, number of vehicles leaving the intersection in the respective directions, and approach speeds.
1.1.11		11.1.2	*Connected vehicles can provide* coordination control, with known platoon sizes and locations.
1.1.11.1	TSP, FSP, EVP	11.5.2	Knowing routes of vehicles requiring priority/preemption allows for prediction and planning in real-time .e.g. preparing for a left turn if several signals upstream along vehicles known route.
1.1.12	TSP, FSP, EVP	11.1.1.2 Others	It is critical to find controller solutions that can combine connected vehicle data with existing sensor data to improve controller performance.
1.1.13	All	11.1.1.2 11.1.3 9.1	Development of new controller algorithms that can make use of connected vehicle data in a less than 100% penetration environment. Need to move away from our current gap based control approach.
1.1.13.1		12.7.1	Agreed. Data should be good for analysis, planning, and operations monitoring.
1.1.14		11.1.2 11.1.3	Added data at the intersection level should allow us to provide improved local adaptive signal control operation.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
1.1.15		11.1.2	Adaptive system timing should be included *in MMITSS ISIG*.
1.1.16			Connected vehicles can provide high-speed transmission of SPaT and of vehicle positioning.
1.1.17		11.1.1.2 11.1.1.3	Connected vehicles can improve intersection control by reducing and eliminating infrastructure based sensors and replacing with vehicle or human based dynamic sensors reducing costs and increasing signal operation efficiencies.
1.1.17.1		11.1.1.2 11.1.1.3	This seems like pie in the sky to eliminate all sensors. *Stakeholder input offers insight on maintaining duality of sensors - CV and existing/fixed sensors.*
1.1.18	TSP, PED, FSP	11.1.1.2 11.1.1.3	Connected vehicles could provide improvement to detection methods.
1.1.19			Connected vehicles can provide better operational control during heavy rains or storms/ construction when loops and video are unreliable.
1.1.20	CC	11.0	Connected vehicles can provide the ability to prioritize vehicles in a multi-modal environment.
1.1.20.1		11.0	I think this is a logical conclusion and should be the focus.
1.1.21		8 13.3.2	Connected vehicles can provide controller algorithm improvements by making use of individual vehicle data that can be provided via a connected vehicle system.
1.1.21.1			It seems like anonymity of the data will limit this significantly.
1.1.22		11.1.2	Use connected vehicle sample speeds for selecting timing program.
1.1.23		11.1.2 11.1.3	Connected vehicles can provide speed information by lane and accurate queue information.
1.1.24		11.1.2 11.1.3	C*onnected vehicles can provide* queue spillback detection between/among intersections.
1.1.25.			Consideration of vehicle weight, performance when traversing the intersection when setting phase length and other settings.
1.1.26		11.1.2 11.1.3	Connected vehicles can provide improved oversaturated control; queue lengths easier to estimate.
1.1.27		11.2.1	Determining the number of vehicles awaiting the left hand turn - and traffic approaching to determine whether a FYA or a protected movement is warranted; detection of speeds to determine appropriate clearance intervals.
1.1.28		11.1.2 11.1.3	Connected vehicles can provide detection of gridlock conditions/violations.
1.1.29		6 5 11.1.3	*Connected vehicles can provide* incident detection where traffic is slow or stopped for prolonged periods of time.
1.1.30		11.1.3	Incident detection *should be included in MMITSS (ISIG).*
1.1.31			Connected vehicles could provide more accurate traffic demand for different movements.
1.1.32		11.1.2 11.1.3	*Connected vehicles can* measure and improve progression through a corridor.
1.1.33		11.1.4	Connected vehicles can provide improved safety - dilemma zone reduction.
1.1.34		11.1.4	*MMITSS should include* better solutions to the dilemma zone problem through use of individual vehicle data available with a connected vehicle system.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
1.1.34.1		11.1.4	It would seem there are some equity issues on this particular application. I am not saying it isn't a good idea.
1.1.35		12.7.1	Connected vehicles could provide measures of effectiveness, such as travel times, to monitor ongoing signal operations. *Signal/System State of Health Monitoring*
1.1.35.1	CC	9.3.3 12.7	One particularly important area that I haven't seen much thought on (Inrix offers this) is the archival data and a notice of effectiveness as it relates to more typical conditions. Also, long term tracking of performance.
1.1.36		11.1.2 12.7.1	*Connected vehicles can provide* measures of effectiveness for section control improvements.
1.1.37		12.7.1	*Connected vehicles can provide* intersection levels of effectiveness, system travel time, and intersection approach information.
1.1.38		11.0 11.0.1 11.1.2	Split or regroup intersections for coordination based on measured MOEs.
1.1.39		12.7.1	*Connected vehicles can provide* travel time/sample speeds for selecting timing programs for section control improvements.
1.1.40		12.7.1	Connected vehicles can provide a lot more data for performance measurement.
1.1.41	PED	11.3.4 11.0	Connected vehicles can provide better coordination between pedestrians and vehicle needs.
1.1.42			Need O-D information (which is prohibited today) to help optimize the network/section.
1.1.43			On-the-fly priority corridor identification, processing predicted O-D data *should be included in MMITSS (ISIG).*
1.1.44			If one were to use the in-vehicle communications - then parking information, event parking information, street closures etc. could be communicated to the individuals or selectively of we had O-D information.
1.1.45	EVP, TSP, FSP	11.0	Multimodal priority is my primary interest as opposed to the auto-based ideas within this category.
1.1.46	PED	11.3.2 13.3.3	Bikes should be considered to be vehicles.
1.1.46.1		11.3.2 13.3.3	Bike should be considered to be vehicles if they are operating in a bike lane or separated bike facility.
1.1.47			Some of the ideas described here concern me. It would seem that some of these should be separated into what the Researchers believe to be true and what is likely to occur.
1.1.48			Larry, there was a harmonization meeting with the Europeans regarding SPaT. They need the changes by end of 2013.
1.1.49			Larry, there are a couple of projects in Europe regarding intelligent signal control with regard to Eco Driving.
1.2			***ISIG Performance Measures and Goals***
1.2.1			Emissions and fuel reductions as well as travel times or corridor throughputs.
1.2.2		12.7.1	Arterial travel-time, degree of saturation, or occupancy on green.
1.2.3			Per person delay versus per vehicle delay.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
1.2.4		12.7.1	Travel time reduction in the network would seem to be the end-users ideal performance measure.
1.2.5			Can we optimize for reliable system-level throughput?
1.2.6			Can the overarching optimization algorithm also throttle data collection in real time to reduce communications costs and data storage costs?
1.2.7			What is the minimum set of data required to realize these applications and can a fixed time interval reporting system feasibly accommodate these data needs?
1.2.8			The problem with these types of projections is that you have to layer on the growth in VMT or shrinkage depending on demographics and the economy - and the cost of mobility!
1.2.9			None of your measures seem to involve safety in any way, are you not short-changing yourselves as to the benefits beyond congestion?
1.2.10			Recall that "8-track" was a clear failure in less than 4 years. *The reference is to music storage and delivery that provided transformative performance in mobile music capability but negligible performance in longevity.*
1.2.11			The first goal might be defining what the goal requires (i.e., a level of percentage population need to determine reasonable data on your five items). For example, if the evening rush hour needs 8% population and you are not there yet, what you ‘can know’ below this tipping point is what needs to be learned first.
1.2.12			Without knowing potential/capabilities from this technology, guesses are not very useful. I would think this is a follow up exercise after we prove we can do it and assess the basic operational aspects.
1.2.13			Picking percentages for improvement or metrics now without knowing capabilities seems like a valueless action - too premature, any guess is good.
1.2.14			Is there any new baseline that "ten years out" we can agree on in any of this?

13.4.2 Stakeholder Input Traceability Matrix – Transit Signal Priority

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
2.1.1		11.2.1.1	Connected vehicle information can provide priority specific to turn movement (i.e., more time needed for right turn).
2.1.2		11.2.1.1 12.6.1	For buses, you can get passenger counts, service type, schedule adherence, etc. *with Connected vehicles.*
2.1.3		11.0	Connected vehicle information should provide service based on vehicle type, loading, schedule delay, etc.
2.1.4		12.6.1 11.0	Connected vehicle information should provide better priority-based service to transit vehicles (compared to current first come first served approach).
2.1.4.1			This is exactly what I think should be an outcome achieved as a part of this project. Find ways to get public sector vehicles equipped and use information strategically to deliver better service.
2.1.5		11.2.1.1	Connected vehicle information can provide priority-level relative to bus occupancy.
2.1.5.1			In Portland, we don't worry about the current occupancy because there is always someone downstream that the bus will pick up. That's a policy distinction that may not be appropriate everywhere.
2.1.6		4.1.2	Connected vehicle information should provide priority only if transit vehicle is delayed.
2.1.6.1		4.1.2	In Portland, the bus system does this. It should be something that would be integrated with the system and in an ideal situation you would also have that data as a signal operator.
2.1.7		11.0	Connected vehicle information should provide the ability to assess speed of various vehicles requesting priority can lead to better assignment of priority in multi-modal environment.
2.1.8	PED		Don't forget to improve pedestrian safety as related to transit vehicle movements. We need to use Connected Vehicle data to better inform the transit vehicle operator and pedestrian to avoid accidents.
2.1.8.1	PED		This is an intriguing concept that I would support.
2.1.9			*Connected vehicle information can improve* communications between bus and transit operation center.
2.1.10			It is not so much the connected vehicle program - but the ability of the appropriate vehicles to communicate their requests in real-time to the intersection/systems to improve their passage, reduce conflicts, avoid accidents, etc.
2.1.11			Connection protection can be improved *with connected vehicle information*.
2.1.12			Connected Vehicle information can improve connection protection to guarantee transfers on low frequency routes.
2.1.13			*Connected vehicle information can provide* better tracking and monitoring of flexible fixed route and demand responsive services.
2.1.14		11.1.3	Bus diversion can be improved *with connected vehicle information*.
2.1.15		11.2.1.1	*Connected vehicle information can provide* more innovative control strategies for transit vehicles (e.g., transit vehicles turning left from the far right lane).
2.1.16			Connected vehicle information can improve conversion from fixed route to para-transit/jitney service.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
2.1.17			*The traffic signal system needs information on* passengers behind schedule or potentially missing connections.
2.1.18			Of course this data will be used, but when a vehicle is not 'behind' this data is also used to sharply reduce any action that might otherwise be taken.
2.1.19		11.2.1.1	*The traffic signal system needs information on* bus occupancy.
2.1.20			*The traffic signal system needs information on* the transit vehicle's route and turn decision (left, right, through).
2.1.21		5 11.0	*The traffic signal system needs information on* the vehicle type and a relative priority based on function or vehicle type - fire truck, ambulance, etc. The vehicle dynamics need to play a role.
2.1.22			In answer to Larry's question, the signal needs to know and will not (never) trust others in this regard in the absence of truth.
2.1.23			*The role of the transit data in making a priority decision* should be balanced against overall optimization -- one of many users.
2.1.24			The request can come from the individual bus/passengers but granting of priority should be made at the infrastructure level (intersection or section or system).
2.1.25		11.2.1.1	I think transit data should be used. I don't think it matters where and what happens on the decision side as long as there is appropriate communication throughout the system to get the information to the right people.
2.1.26	Freight		This decision must he shared - the vehicle does not know the balance of the service requests - - so it is broader - because it involves the route, the intersection, the section - not just the intersection. The vehicle type and priority should have a greater impact - it becomes more complicated when you try to integrate freight priority!
2.2			***Transit Priority Granting***
2.2.1			Of course not! *Should priority be granted to every qualified vehicle.*
2.2.2			If it is light rail, perhaps. If it is bus, then no.
2.2.3			How do you define "qualified"?
2.2.4			Consider not only if the bus is ahead or behind schedule, but how the travelers are doing (if they have a logged itinerary) with respect to schedule or planned connections.
2.2.5			Consider number of passengers on the transit vehicle.
2.2.6		11.0	The ideal priority solution would combine the needs of approaching transit vehicles with those of other road users.
2.2.7	All	11.0 11.2.1.1	Assign priority based on existing traffic conditions at that time.
2.2.8			There needs to be a budget. But, it is likely that the optimal solutions are route, as well as localized issues. So, broadband communications and DSRC are likely to be required.
2.2.9			If you are going to grant priorities during peak periods, this needs to be considered during the planning of operational parameters to budget these times.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
2.2.10			I think this is something that is user-definable based on policies by the transit agency.
2.3			***Transit Performance Measures***
2.3.1			On-time performance, number of successful connections made, ratio of transit travel time to POV travel time are performance measures for Transit Vehicle Priority.
2.3.2			And again, we are using delay as the measure of success rather than safety at all.
2.3.3			Again, how do we know without assessing the basic capabilities?
2.3.4			Intuitional trust by a multiple local agency of a transit agency that cover them seems very unlikely to occur, even in ten years. If the transit vehicle states why it needs a call (I am behind and I have xx people on board), then it seems likely that the ASC will be able to grant without understanding the need further.
2.4			***Transit - Other***
2.4.1			Note that much of the discussion focuses on the use of near-field/DSRC communications with the intersection. Yet the scenarios shown (for a section-route) are more of a central directed function. So, it becomes the ability of the vehicle to communicate its needs to the central system so that it can "program" the route, manage potential conflicts and actually dynamically re-route the vehicle if necessary.
2.4.2			There is a wide body of knowledge on transit signal priority applications. This is often the most common application sited for connected vehicle use.

13.4.3 Stakeholder Input Traceability Matrix – Pedestrian Mobility

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
3.1			***Pedestrian Communications***
3.1.1		5 6 9.1	The communications method needs to be cost effective, easy to use, and made available to all pedestrian users. It must be a technology and solution that is also easily used by someone with limited visual capabilities.
3.1.2	CC		Is there a latency requirement for pedestrians that would suggest one communications alternative over the other?
3.1.4			It will depend on the latency necessary for the application to receive data, process it and then provide feedback to the pedestrian in a timely manner.
3.1.5			Advisory or "active safety" warning systems? It depends on the applications you are considering.
3.1.6	CC		DSRC is better for safety. Wi-Fi can take too long to make the connection. 3G/4G is not always available or can be dropped.
3.1.7	CC		Wi-Fi has the correct range and is already on most devices!
3.1.7.1	CC		The user has to enable the Wi-Fi to be on. It also makes battery life less and could be prone to issues.
3.1.8	CC	9.1	All of the above communication methods and others not yet known. I still fail to see the need to pick the winner here when the application and the ConOps are still quite young.
3.1.9			Whatever *communication method* has the best security.
3.1.10		9.1	Because it is not reasonable to require a pedestrian to have a special device just for walking around, we should use communications that people would have anyway for consumer reasons. This would suggest 3G/4G, Bluetooth, or Wi-Fi.
3.1.11		9.1	It is probably best to test some combination of wireless technologies and see which works best. The solution could include more than one too.
3.1.12		9.1	Wi-Fi is good. It's on most smart phones and has enough range.
3.1.13		9.1	Probably Bluetooth or 3G/4G.
3.1.14		9.1	*(ConOps Workshop)* DSRC can be used similar to cell phone communication.
3.2			***Pedestrian Intersection Control Improvements***
3.2.1		11.0.2	On-demand all pedestrian phases, predictive pedestrian phase lengths, and/or 2-minute look-ahead pedestrian movement predictions are intersection control improvements that could benefit pedestrians.
3.2.2		11.3.2 9.3.6	Extend phase length for slow-moving pedestrians.
3.2.3		9.3.6	Do not increase phase lengths for every type of pedestrians.
3.2.4		11.0.2	Better knowledge of true pedestrian demand at an intersection could provide improvements at the controller level (get past our current fixed time approach).
3.2.5		11.0.2	Knowing the full crossing pattern as opposed to single approach crossing is an intersection control improvement that could benefit pedestrians.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
3.2.6		11.0.2	On-demand and adaptable intersection control improvements could benefit pedestrians.
3.2.7		11.0.2	Better dynamic service time to pedestrian movements (adaptable Walk/Don't Walk) is an intersection control improvement that could benefit pedestrians.
3.2.8		11.0.2	Better knowledge of vehicle positions and speeds should theoretically allow shorter cycle lengths for the same performance. That would improve pedestrian LOS more than anything else.
3.2.9		11.3.4 13.3.3	If possible, integrate severe-weather information into the phase length determination. Imagine crossing the street with a Chicago-style headwind, an icy surface, or Monsoon-type water hazard (puddle size and water flow rate). Standing on the street corner in Tucson during or after rainfall is an invitation to a “vehicle shower” or spraying. Imagine the pedestrian benefit of reducing the wait-time during inclement weather.
3.3			***Disadvantaged Pedestrian***
3.3.1			They are the only ones that it makes sense to assist!
3.3.2			This is an area where the 'kinds' of disability need more agreement so that we can work up to saying what we will not in fact do (or cannot do).
3.3.3		9.3.6	Require that the handicapped have the device - keep conventional devices - but enhance available walk and clearance time to manage special cases only.
3.3.4			Meet ADA requirements with hardware less likely to get knocked over by vehicles and less likely to annoy neighbors of the signal.
3.3.5		11.3.4	Curb cut information, sidewalk closures, icy/wet crosswalk or sidewalk conditions are additional considerations that could be made for disadvantaged pedestrians.
3.3.5.1		11.3.4 13.3.3	This seems like a pretty difficult hurdle to overcome. How would you get information on icy crosswalks? Closed sidewalks would be good.
3.3.6			Log all special services and note where basic services are lacking so they can avoid these intersections altogether.
3.3.7		11.3.2 13.3.3 9.3.6	Which street they are facing, which phase is currently active, and vehicles violating the pedestrian phase are additional considerations that could be made for disadvantaged pedestrians.
3.3.8		11.3.2 13.3.3 9.3.6	Use GPS on their phone to tell them if they are straying out of crosswalk.
3.4			***Pedestrian Performance Measures and Goals***
3.4.1		9.3.6	Pedestrian accessibility, by level of ambulatory capability
3.4.2		11.3.2	High level of equipped pedestrians
3.4.3		Scope	Fewer injuries for the handicapped.
3.4.4			This really needs to be more than just pedestrians - - fewer injuries with less wasted capacity!
3.4.5			Improving safety for pedestrians should be a performance measure more so than reducing pedestrian delay.
3.4.5.1			An argument for reduce delay leads to better compliance of pedestrian signal indications.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
3.4.6		11.0.2 12.7	Better service level or performance measure level for pedestrians without impacting vehicle travel time.
3.4.6.1		11.0.2 12.7	This is a value choice that should be made at the policy level. In Portland, there are places where we would disagree with this. Also, in the late night operations, why would one vehicle be more important than one pedestrian?
3.4.7		11.0.2 12.7	Is delay the only performance measure? It may not only be about delay but more about safety. Their delay may actually be longer rather than shorter. If we find there is only one pedestrian at a light it may take longer for them to cross.
3.4.8		4.1.3	Can we measure the goal in term of platooning pedestrian movements in downtown areas in some useful way?
3.4.9			Pedestrian Safety is more important than mobility.
3.4.10		4 9.1	Give consideration of how remote devices would interface with the traffic controller and how that might affect standards.
3.4.11			I sometimes wonder if we are spending too much time staring at devices rather than looking around in our environment.
3.4.12			Pedestrians should not have to stare at the device to know signal status. The device should work unobtrusively and alert only when there is conflict.
3.4.13		11.1.3	Any improvements will be very dependent on penetration. This is an area that I don't think has been researched.
3.4.14		9.3.6	Do not focus on the able bodied - if they are too stupid to press a simple button why give them a tool to really mess things up!
3.5			***Pedestrian - Other***
3.5.1		11.0.2 4.1.3 11.3.2	*Connected vehicles can provide* pedestrian wave accommodation (special events).
3.5.2			There are plans to include a pedestrian/transit vehicle safety application during the Connected Vehicle Safety Pilot. The goal is to study how V2I data could improve transit vehicle versus pedestrian accidents in crosswalks.
3.5.3			You should add the technology (from Israel) being used by FTA to detect pedestrians at intersections as part of the Safety Pilot Model Deployment in Ann Arbor.
3.5.4			There are pedestrian applications being researched at the University of Idaho and University of Minnesota. There was a presentation at the ITS America Conference regarding a mobile APS application developed at the University of Minnesota.

13.4.4 Stakeholder Input Traceability Matrix – Freight Signal Priority

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
4.1.1			I think transit, freight, emergency, and maintenance vehicle priorities are really very similar from a technical level of traffic control. The operational priorities - business rules - dictate priorities.
4.1.2		8 5	Freight is too narrow a theme. What about construction equipment, road and winter maintenance vehicles, and other types of heavy vehicles. Truck signal priority would include freight and all classes of heavy vehicles excluding transit.
4.2			***Freight-Traffic Management Strategies***
4.2.1			*Strategies* similar to transit vehicles, but they may be at a low priority because these are run by private for-profit organizations.
4.2.2		11.0	Considerations should be made on the operations of the terminals or ports where freight is operating in and out. Example ship arrivals, train arrivals at intermodal facilities, etc. These operations present large areas of congestion around these facilities.
4.2.3		11.4	Truck turning radii should be taken into consideration near freight facilities when signal timing is set.
4.2.4		11.4	*Traffic management strategies* should strive to make safety improvements for heavy vehicles approaching intersections.
4.2.5			Truck intersection safety improvements at downgrade approaches especially in mountainous areas.
4.2.6		11.4	*Traffic management strategies that incorporate* consideration of truck acceleration and deceleration times.
4.2.7		11.4	*Traffic management strategies should incorporate* dynamic stop bar locations to provide acceptable turning movement for freight movements, say sharp left hand turns.
4.2.8		11.4 11.0.1	Avoid having trucks come to a full stop.
4.2.9			Trucks maybe should get a longer yellow indication because they are less inclined to stop.
4.2.10			Dilemma zone elimination for trucks.
4.2.11		11.0.1	Increased green time during peak periods of freight traffic will keep trucks moving.
4.2.12			MNDOT studies found that providing priority to trucks increased the signal cycle length, resulting in increased delay to other vehicles that approximately cancelled out the benefit provided to the trucks.
4.2.13		11.0.1	Identify trucks and/or large and heavy vehicles through the intersection and allow appropriate passage time automatically.
4.2.14			Travel time information provided trucks for various routes would be advantageous.
4.2.15		11.0.1 11.4.2	Given the density, one would want to platoon these vehicles to create a smoother travel through the network - basically granting them with a priority if one could work with the entry and dispatch process to group the vehicles.
4.2.16			Can multiple truck from or to (OD pairs) be treated in some useful way to increase laminar flow types?
4.3			***Freight - Connected Vehicle Information***

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
4.3.1	ISIG		*Connected vehicles* can provide optimization based on number of commercial vehicles.
4.3.1.1			O-D info and schedule adherence requirements could be fed into algorithms.
4.3.2		11.4.2	Ability to detect vehicle class, speed, etc. would enhance safety.
4.3.3			Schedule criticality, vehicle size and weight, turning radius, and acceleration/deceleration performance information will enhance traffic control strategies for trucks.
4.3.4		11.4.2	Speed, weight, and dimensions information will enhance traffic control strategies for trucks.
4.3.5		11.4.2	One needs more vehicle dynamics - breaking distance, mass, immediate speeds, etc. so that clearance times and progression speeds can be managed.
4.3.6		11.4.2 11.4	Having data on the vehicle type and potentially load or information on stopping ability could help us improve control decisions at the intersection.
4.3.7			Maybe something on criticality of cargo, for example perishable items, medical, etc. will enhance traffic control strategies for trucks.
4.3.8		11.0.1 11.4.2	Current lane and direction of travel information will enhance traffic control strategies for trucks.
4.3.9			Turn radius, speed, and lane being occupied information will enhance traffic control strategies for trucks.
4.3.10		11.0.1	The expected/desired path through the network will enhance traffic control strategies for trucks.
4.3.11			When a signal knows a truck is arriving, it can adjust its assumptions for startup, clearance time, and other factors for that particular phase.
4.3.12			Fewer emissions (e.g., priority to trucks on an uphill approach) information will enhance traffic control strategies for trucks.
4.3.13			Shouldn't this information already be taken into consideration by dispatchers? Is it necessary for trucks to be connected vehicles?
4.3.14			Assumptions that are being made are not realistic. In particular, in V2V we are struggling with how to identify what’s being pulled – communication issues are huge. Cargo ID is also a challenge – hazmat maybe not so much, but shippers don’t want to give out info on what they are carrying with a HUGE benefit. More understanding of the industry (and not what the states want) is needed.
4.4			***Freight Priority Requests***
4.4.1		11.0	Need to establish some measure to determine if and when trucks should be given priority.
4.4.2			Trucks should request priority similar to transit and emergency vehicles only at peaks during the day where operations of terminals cause congestion.
4.4.3			In the off-peak, yes, especially if a train or ship they are delivering to are scheduled to leave shortly.
4.4.4			Yes, *trucks should be able to request priority in a manner similar transit and emergency vehicles,* but they should be granted low priority.
4.4.5			No but in a safety scenario where the green could be extended for a truck that may not be able to stop.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
4.4.6		11.0.1 11.4.2	There are other considerations - suggest mandating platooning rather than random dispersion!
4.4.7			There should be an economic factor as well, so trucks could pay more for priority when they have a time-critical load.
4.4.8			MNDOT had good success in using two loop detectors 30 feet apart in the approach lane. Cars were too short to trigger both loops simultaneously. It was a low cost easy way to detect trucks in advance of the intersection.
4.5			***Freight - HazMat***
4.5.1	ISIG		The type of HazMat (flammable, etc.) is connected vehicle information that could be used to make traffic management decisions. The more dangerous the cargo is, the higher its priority.
4.5.2			Suggest also adding oversize and overweight trucks that require permits from DOT specific to trips they make.
4.5.3	ISIG	11.0.1	Do you really want to grant priority for HAZMAT at all intersections? Obviously there is a need to track this cargo through the network and to take this movement in account for TSP or EVP - so as not to create a dangerous situation.
4.5.4			Please keep in mind that greater than 90% of all hazmat is NOT placarded or marked. Only a very small amount should get signal treatment.
4.5.5			Making traffic system operator aware of HAZMAT vehicle being present in the system/network might be of help.
4.6			***Freight Priority Performance Measures and Goals***
4.6.1		12.7.4	Delay management is a realistic performance measure.
4.6.2		12.7.1 12.7.4	Should not just measure truck delay, but also the total delay at the intersection? Decreasing the truck delay can increase delay to other vehicles.
4.6.3		12.7.4	Accident rates at intersections, minimized stops - so stops is a good measure. I am not sure that travel time is the measure - waiting time is. But, where you place the waiting time is important - at start or end is the best - not at random locations throughout the network?
4.6.4		12.7.4	Freight/goods reliability by time of day and condition (rain, special event, etc.) are realistic performance measures.
4.6.5		11.0.1 11.0.2	With all due respect, you have a school there that dumps vehicles out. Use that situation like someone might use the corridor in Long Beach that loads and offloads shipping containers form the harbors. Set up a test that note the clearance time pre/post to clear the day's load out and compare that with the impact on the cross street in some way.
4.7			***Freight - Other***
4.7.1			Here are links to 2 Minnesota projects on truck priority at traffic signals: http://www.dot.state.mn.us/guidestar/2006_2010/truck_priority.html http://www.dot.state.mn.us/guidestar/2001_2005/truck_priority/truckpriority final.pdf

13.4.5 Stakeholder Input Traceability Matrix – Emergency Vehicle Preemption

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
5.1			***EVP - Connected Vehicle Information***
5.1.1			*Connected vehicle information can* better handle priority service for all types of Emergency Vehicles (fire versus police versus ambulance, etc.).
5.1.2		11.5.2	*Connected vehicle information* should be able to better facilitate route priority for emergency vehicles.
5.1.3		11.5.1	Ideally we should handle emergency vehicle service as a priority over preemption.
5.1.4		11.5.1	*Connected vehicle information* can eliminate preemption in non-emergency situations.
5.1.5		11.5.1	*Connected vehicle information can* ensure that pre-emption is used by only approved vehicles.
5.1.6		11.5.1	CV allows for arbitrary phase order, which should speed up coordinated system recovery after preemption.
5.1.7		11.5.1	*Connected vehicle information can provide* quicker transition into and out of preemption.
5.1.8	CC	11.5.2	Preemption could be improved by taking into account the vehicle's planned route. For example, optical preemption affects all the signals within some distance straight ahead of the emergency vehicle, even if the vehicle will be turning at the nearest intersection. Instead, you could preempt the signal around the corner (assuming you can get DSRC to work around corners with buildings!).
5.1.9		11.5.2	Alerting vehicles of impending conflicts - and routing complete O-D solutions for each vehicle. Again, this needs broadband communications and network management (traffic) so that EVP is not just a local issue.
5.1.10		11.5.2	Vehicle O-Ds and complete paths can be used to anticipate system-level effects/response.
5.1.11		11.5.1	*Connected vehicle information can provide* better handling of priority at intersections when multiple EVs arriving from multiple directions and at different times.
5.1.12		11.5.2	C*onnected vehicle information can improve preemption/priority* by providing route information back to EV operators so they can make better informed dynamic re-routing decisions (such as if approaching a rail crossing that is under control).
5.1.13		11.5.2	Connected vehicle information can provide dynamic mainline/progression routing from vehicle to scene.
5.1.14			Two-way communication with the EV driver to let them know status of request *could improve preemption/priority.*
5.1.15		6 8	Existing road conditions will be better known with connected vehicles.
5.1.16		11.5.2	Have the EV OBE transmit its location, heading, vehicle class, and incident location they are responding to. Then, the traffic signal can make a decision based on vehicle class which vehicle to give priority to.
5.1.17		11.5.1	*Connected vehicle information* can eliminate field infrastructure for some existing technology.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
5.1.18			As vehicle pass by the RSU of the signal control and ask for preemption or priory they will state their agency affiliation (in the DSRC messages). The RSU should gather this for DOT use to know who has arrived on scene (the way they came in). This is vital in some incidents to know very quickly and relate to other (IC and back office).
5.2			***EVP - Priority Contention***
5.2.1			Vehicle class/type, incident location and type, severity of incident etc. will help the traffic control decide whether to grant priority or not and if yes, which EV to give priority to.
5.2.2			Mostly vehicle type, ability to stop, and predicted time-to-intersection should be considered in determining priority.
5.2.3			Vehicle type versus class of emergency being serviced *should be considered in determining priority.*
5.2.4			EMTs first, followed by Fire s*hould be considered in determining priority.*
5.2.5			Link *priority decision* to data from emergency dispatch regarding the level of the emergency response (e.g., fire versus a cat stuck in the tree).
5.2.6		11.0 9.3.4 9.3.5	There must basically be an off-line discussion of priority - i.e., the region needs to establish a priority scheme for its operations (not just vehicles - but vehicle and mission) so that the prioritization can take place at a higher level and even alternate routes can be suggested or required. EVP is not just a localized problem - it needs to be handled for routes!
5.2.7			*Priority contention for several requesting vehicle should consider* adherence to predicted route.
5.3			***EVP - Performance Measures and Goals***
5.3.1		12.7.5	Response time improvement.
5.3.2		12.7.5	Reduction in response time (2)
5.3.3			Improved system recovery from preemption.
5.3.4			Accessibility measures -- how far can a single vehicle reach from its home base, reliably across the network within a specific response threshold?
5.3.5		12.7.5	Reduced accident of EVP actions at intersections is about the only measure. We already have EVP and route EVP which grants green-waves, etc. About the only benefit that could be added is to route other vehicles away from the area. How does one measure those?
5.3.6			I think people are being far too optimistic on gains for EVP.
5.3.7			Not all response vehicles arrive at the same time, by design, nor do they come/leave at the same speed or stage at the same places. See IEEE work for some concept to perhaps steal or reuse.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
5.3.8			A major problem in emergency vehicle coordination credentials and rights is those “out of home service” vehicles come and operate in the region during regional problem (seasonal fires are good example). We need a solution that accepts this reality and the different equipment types that often need to cooperate.
5.3.9			In general, performance measures should be based on impacts to non-priority vehicles.

13.4.6 Stakeholder Input Traceability Matrix – Other

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
6.1.1	All	8	Weather conditions affecting signal clearance durations should be considered.
6.1.2	All		Weather/roadway flooding *should be considered.*
6.1.3		11.2.2.1 13.3.2	Highway-Railroad Interface
6.1.4		11.2.2.1 13.3.2	Highway-Railroad Interface - Agree with this topic. Signal priority to clear waiting areas for signals that cross over a rail grade crossing very important. Also, once train is occupying crossing and blocking road, signal would give priority to cross traffic until train clears crossing.
6.1.5			Prior knowledge of train arrival at crossings to be able to perform pre-preemption and post-preemption timing plans.
6.1.6			Better exchange of data between rail side and controller to ensure the safe and efficient operation of signals at an active rail crossing.
6.1.7			Interconnected grade crossings and traffic signals where queue space must be forced off due to potential train/vehicle collision - railroad preemption.
6.1.8			At-grade, non-equipped crossings remains a big issue to Federal Railroad Administration that may benefit from DSRC but I am not sure how as I type this.
6.1.9			Reconfiguration of at-grade crossings, especially those near traffic signals, must be designed for all vehicles, not just cars.
6.1.10			We should include interconnected traffic signals and grade crossing locations with gates/lights/traffic signals (i.e., railroad preemption).
6.1.11			Special events (without being told explicitly that it’s a special event) should be considered.
6.1.12		11.1.1.4	Arterial-Freeway Interchanges
6.1.13		11.1.1.4	Suggest including ramp meters to the system
6.1.14		11.1.1.4	Ramp meter spill back and ramp meter priority s*hould be considered.*
6.1.15	EVP		Alternate routes for EVP and incident mitigation should be considered.
6.2			***Other - Special Classes of Users***
6.2.1			Should we be giving priority to these special classes of vehicles/situations or rely on the overall system improvements to better serve these special cases?
6.2.2			Yes - EVP routes - most systems can support this now - the connected vehicle simply adds the en-route tracking.
6.3			***Other - Special Cases of Traffic Management***
6.3.1			Active Traffic Demand and Management
6.3.2			This is an important area, maybe check into the experiences of recent evacuation events for insights
6.3.3			This is just a better opportunity to communicate into the vehicles if they have in-vehicle displays.
6.3.4	ISIG		Incident detour traffic management should be considered.
6.3.5	PED		Don't forget the pedestrians in the concept of "traffic."
6.3.6			Signal operations while signal is under maintenance or in flash should be considered.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
6.3.7			As mentioned in another post, work zone and many other events overlaid with signal operations in a clear way remains to be developed and the test beds should support this need.
6.3.8			Should the system include a “surveillance” function?

13.4.7 Stakeholder Input Traceability Matrix – Cross-Cutting Issues

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
7.1			***Cross-Cutting - Communications***
7.1.1			There are already commercially available transit signal priority/emergency vehicle preemption systems that use GPS and radio communications with the signal. It would be useful to work with these vendors to incorporate DSRC rather than try to re-invent the whole system just to use DSRC.
7.1.2			Many of these applications need not be DSRC centric - but rather in an urban setting, this is more likely a broad-band communications using on-board GPS and better location etc. to support priority and preemption without localized infrastructure. A DSRC centric is not an optimal solution unless you suggest that SPaT is present!
7.1.3			DSRC may have difficulty communicating around corners in downtown areas
7.1.4			Do we have good technical data on the density of DSRC and vehicles around an intersection - within range?
7.1.5			Since many intersections have communications lines already in place, perhaps a more robust method of using DSRC is needed than cascading the information intersection to intersection.
7.1.6			Is it really practical to equip all of the signals in an urban environment with the DSRC/SPaT - or are we going to see advances in broad-band communications that will make this more practical?
7.1.7			Not significant - broadband is more likely a deployment alternative in urban settings (in comparison to the DSRC mentioned in the scenario description.)
7.1.8	Transit		Will DSRC give us the distance needed to solve both transit signal priority under all conditions (including environmental)? The stated range for 5.9GHz DSRC is 1000 meters (30 meters for 915MHz predecessor).
7.1.9	ISIG		Standards - NTCIP 1103 V3 is critical.
7.1.10	ISIG		Expansion of NTCIP 1202 to add support for SPaT is an outcome of the Battelle SPaT work. Funding is to be available for updating 1202. Hopefully the SPaT additions will be a focus of this funded effort.
7.1.11			A wealth of safety information could be gained from I-to-V communication, for example operator behavior could be identified, and corrective actions taken within transit fleets using collected data.
7.1.12			Perhaps learn when we need to equip and when we do not is the key research need in this regard.
7.1.13			A NHTSA decision in 2013 could mandate V2V on new vehicles. It will not likely mandate any V2I applications. Therefore, even the equipped vehicles may not be capable of interacting with the roadside infrastructure for V2I apps. We need to identify a mechanism for getting the V2I apps into the vehicles.
7.1.14	ISIG	5	In theory all aspects of traffic signal control can be improved with Connected vehicle information.
7.1.15		11.5 11.0.1	*Connected vehicles can provide* coordinated priority through the section by path for time critical users (freight, transit, EV).
7.2			***Cross-Cutting - Data and Information Security***

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
7.2.1		9.3.2	What about data security? This is subject to much corruption?
7.2.2		9.3.3	All of *the data should be archived* - this effort helps us collect data to analyze the signal and traffic operations that will help answer the questions you asking beforehand that we really can't intelligently answer at this point.
7.2.3		9.3.2 9.3.3	Keep data disaggregate but anonymous.
7.2.4		9.3.2 9.3.3	Data should be open and shared.
7.2.5		9.3.2 9.3.3	Keep all data (everything) in a standardized format.
7.2.5		9.3.3	*MMITSS project* needs to be careful about what data is archived due to FOIA. You do not want to get called into court for every traffic accident.
7.2.6		9.3.3	*MMITSS project will* want to keep performance measure data.
7.2.7		9.3.2 9.3.3	Government generated date is equivalent to public data and should be freely available. We can also expect private concerns to merge/fuse the data to provide added value!
7.2.8		9.3.3	*Archive r*eal-time 24x7 continuously.
7.2.9			*Archiving frequency* depends on type of data. Follow Section 1201 for real-time data.
7.2.10		9.3.3	*The data should be archived* long enough for folks to use it throughout the R&D process of connected vehicles.
7.2.11		9.3.3	*The data should be archived* indefinitely.
7.2.12		9.3.3	When stripped of PII, keep data around to support longitudinal performance assessment.
7.2.13			I may be on the fringe here, but I don't think a signal should have to archive much, if any, data to operate effectively. The goal should be to "forget" as much data as soon as possible to protect privacy.
7.2.14			A signal's internal logic should be enough to manage traffic effectively. I don't see any need to store vehicle data at the signal-level. Data should be "forgotten" as soon as possible.
7.2.15		9.3.2 9.3.3	Security *protection* from hackers s*hould be included in the security requirements for archived data.*
7.2.16		9.3.2 9.3.3	Privacy of data will be a critical issue to public acceptance of the end system.
7.2.17			I am not sure we have agreed on who owns data being broadcast by vehicles, individuals, and fleets. Consequently, maybe we don't have any authority to capture or archive data?
7.2.18		9.3.2 9.3.3	There should be no implied ownership. If it is publically collected, it is freely available to the public and that needs to be part of the O&M costs associated with the data. A better question - who will bear the cost of creating and maintaining the database?
7.2.19		9.3.2	Each agency/company should have their own policy on security and privacy of data.
7.2.19.1		9.3.2	With respect to comment #1, there will need to be a uniform policy on security and privacy nationwide. I don't think leaving it up to each agency will work.

Input ID#	Related Inputs	ConOps Mapping	Stakeholder Input/Feedback
7.2.20		12.7.6	How do we police the accuracy of the data provided? Bad data can make the archive worthless!
7.2.21		9.3.2 12.7.6	The integrity of the data must be guaranteed - but everyone should have access - no restrictions! The major issue is who certifies the integrity of the data.
7.2.22		12.7.6	Quality of the data is key.
7.3			***Cross-Cutting - Maintenance and Operations***
7.3.1		12.5.1 12.2 12.3	This is a completely new requirement (i.e., communications management) for transportation agencies and may be somewhat challenging for some agencies. We need both operational and performance expectations identified.
7.3.2		12.5.1	Any DSRC used for safety applications will make maintenance of the DSRC a high priority item, which may be difficult with limited maintenance staff. It also may involve different staff skills than currently employed for signal maintenance.
7.3.3		12.5.1 12.2 12.3	Communications issues for remote, rural locations and smaller communities are maintenance and operations issues that need to be included *in the MMITSS ConOps.*
7.3.4		12.5.1 12.2 12.3	Do the agencies have the communications expertise to support this stuff?
7.3.5			Beware of high levels of availability - traffic cabinets and traffic field equipment often takes serious time to fix - sometimes days!
7.3.6			Most of our traffic signals do not have internet connectivity. Providing such internet connectivity for every roadside DSRC will be a big issue.
7.3.7		12.7.6	If you get the internet, you also get time sync. How many intersections would benefit from a simple external time sync and not any internet connection? Is this a real problem or one that clearly will get solved by other means over the ten year time frame?
7.3.8		12.2 12.3	Certification of equipment is essential; ongoing calibration and easy swap maintenance is required.
7.3.9		12.7.6	*MMITSS project* may need to provide performance measures as to repose and turnaround time to maintenance of an equipped intersections due to safety implications.
7.3.10		5 10.1	It seems that the area of work zones and incident management when overlaid on a signal control areas is a major missing element in your list. We would want the test bed to be in a position to be able to study this further.
7.3.11			How do we factor in possible lessons learned from the Safety Pilot (timing of this project versus Safety Pilot could be an issue)?
7.3.12			It is important that the lessons learned are practical for the rank-and-file deployers - not just the "bleeding edge" agencies such as MNDOT.